39th International Free-Electron Laser Conference

FEL19

Hamburg, Germany

26-30 August 2019

Universität Hamburg, Main building

Conference Guide
&
Abstract Booklet

European XFEL

DESY.

FEL19

39th International Free Electron Laser Conference
26 – 30 August 2019

Universität Hamburg, Main Building
Edmund-Siemers-Allee 1
20146 Hamburg

https://www.fel2019.org/

Conference Guide
&
Abstract Booklet

Contents

Welcome

On behalf of the Local Organizing Committee, we are pleased to welcome you to the
39th International Free Electron Laser Conference (FEL2019)
in Hamburg, Germany.

The Scientific Program Committee has created an exiting program focusing on recent advances in free electron laser theory, experiments, electron beam, photon beam and undulator technologies, and applications of free electron lasers.

We welcome more than 350 delegates from FEL facilities, research institutions and universities around the world. In addition about 30 companies will show their products during the industrial exhibition.

The conference includes a tour of the local FEL facilities FLASH and European XFEL.

Hamburg is the 2nd biggest city in Germany and you can enjoy its international and maritime flair and explore a rich cultural scene.

Willkommen in Hamburg.

Yours sincerely,
Winni Decking & Harald Sinn

Chaired by DESY and European XFEL

Conference Organization

Local Organizing Committee
Conference Chairs: Winfried Decking (DESY) & Harald Sinn (European XFEL)
Administrative Chairs: Matthias Kreuzeder & Katharina Kucza
Conference Secretariat: Christel Övermann & Katrin Lando
Computing Services: Carsten Kluth
Proceedings: Michaela Marx & Ruth Rudolph
Student Grants: Jörg Rossbach
Poster Sessions: Thomas Wamsat
Presentation Manager: Riko Wichmann
Speaker Preparation: Oliver Koschig
Lab Visits: Dirk Nölle & Rolf Treusch
Auxiliary Support: Rebecca Jones-Krueger, Hannah Gerth
Abstract Booklet: Michaela Marx, Winni Decking & Volker Schaa

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J.N. Galayda, SLAC
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Conference Organization

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Svitozar Serkez, European X-Ray Free-Electron Laser Facility
Oleg Shevchenko, Budker Institute of Nuclear Physics
Frank Stephan, Deutsches Elektronen-Synchrotron
Takashi Tanaka, RIKEN Spring-8 Center
Dong Wang, Shanghai Institute of Applied Physics, Chines Academy of Sciences
Sverker Werin, MAX IV Laboratory and Physics Department, Lund University
Ying K. Wu, Duke University
Juhao Wu, SLAC National Accelerator Laboratory
Alexander Zholents, Argonne National Laboratory

FEL Prize Committee

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Bruce Carlsten, LANL
Marie Emmanuelle Couprie, SOLEIL
Hiroyuki Hama, Tohoku University
Mikhail Yurkov, DESY

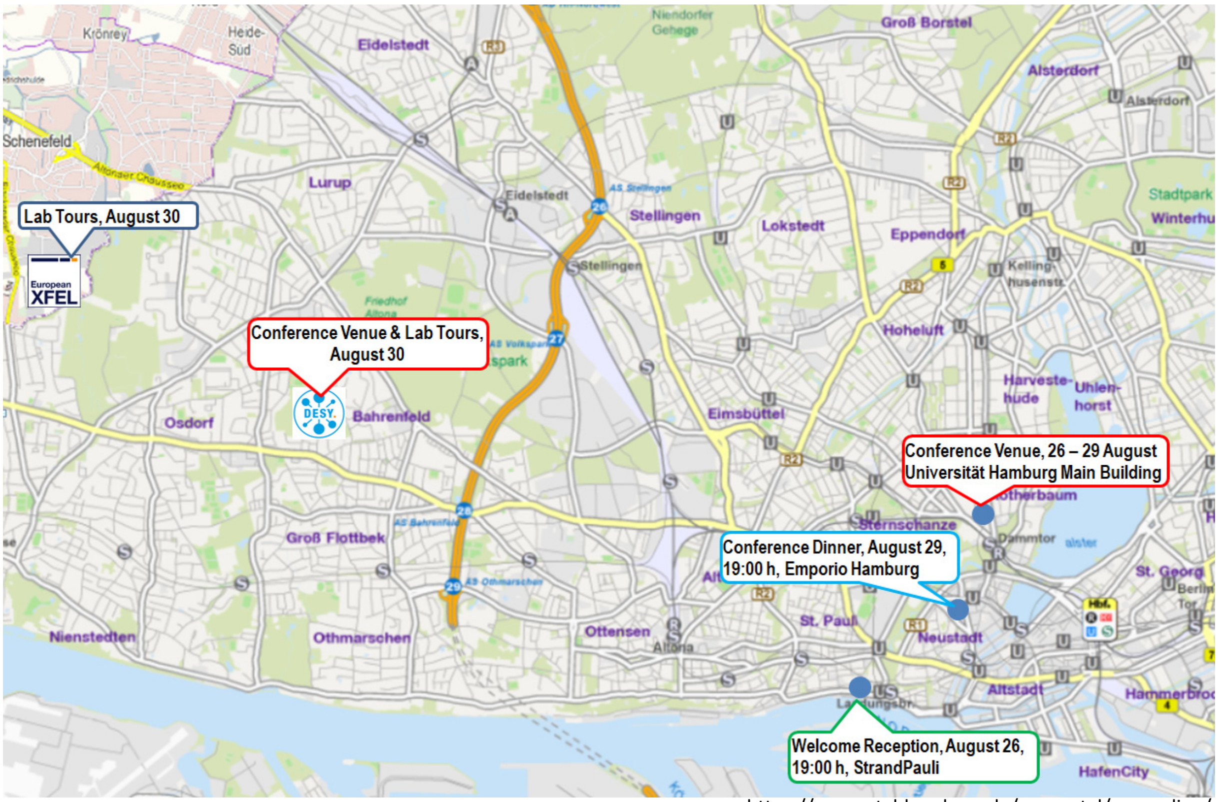
Conference Venues

The conference will take place at the Hamburg Universität Main Building, located in the city center. We will be on the University's campus for four days, from August 26th to August 29th.
The DESY campus will be the venue for the last day of the conference, on August 30th.

The addresses of the conference venues are as follows:
Universität Hamburg
Edmund-Siemers-Allee 1
20146 Hamburg

DESY
Notkestr. 85
22607 Hamburg
The main auditorium is located in building 5

Overview of all conference venues and the locations for the social events:



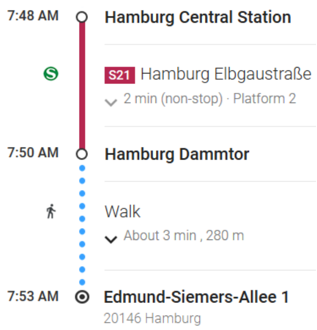
https://geoportal-hamburg.de/geoportal/geo-online/

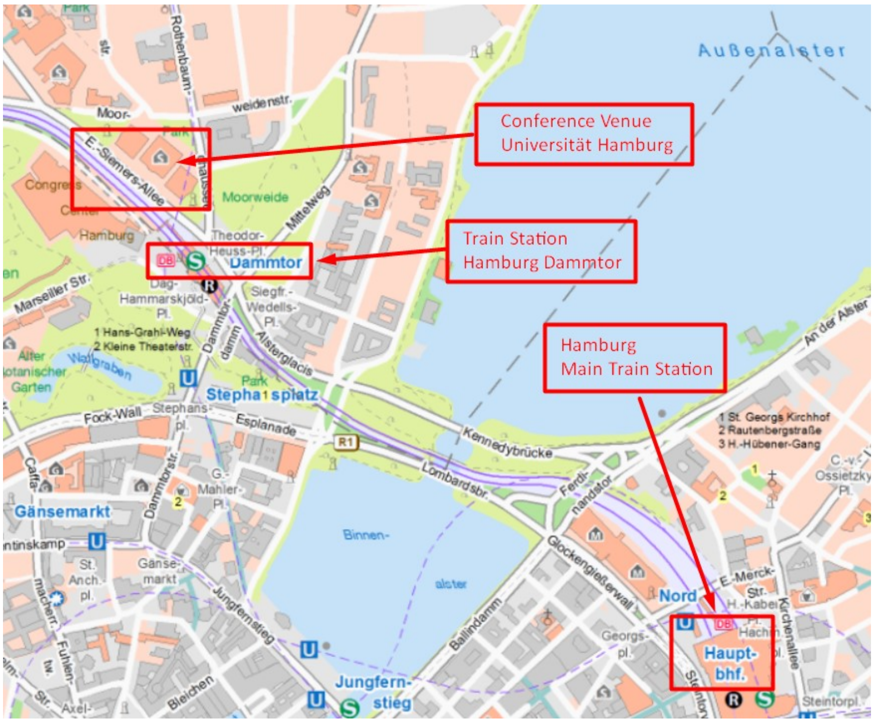
Transportation to the Venues

Arriving by Train (at Hamburg Central Station)

There are three suburban lines (S11, S21 and S31) operating between Hamburg Central Station and Dammtor Station (Hamburg University), please see www.hvv.de/en/.

Take S11 in the direction to Blankenese and leave at the 1st stop
or
take S21 in the direction to Elbgaustraße and leave at the 1st stop as shown in the example on the right
or
take S31 in the direction to Altona and leave at the 1st stop.
All trains take three minutes followed by a short walk (3 min.) from the train station to the venue.

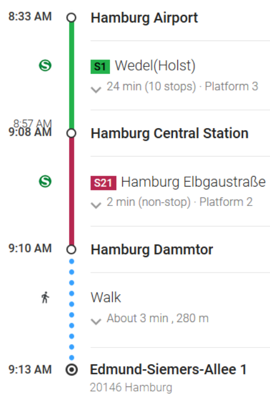




https://geoportal-hamburg.de/geoportal/geo-online/

Arriving by Plane

From Hamburg Airport take train S1 (the green line) and leave S1 after 10 stops at “Hamburg Central Station”. Change here to train S21 (the pink line) and leave S21 after 2 stops at “Hamburg Dammtor”.
It’s a short walk (3 min.) from the train station to the venue.
In total the trip takes about 40 minutes.



Arriving by Taxi (from the airport)

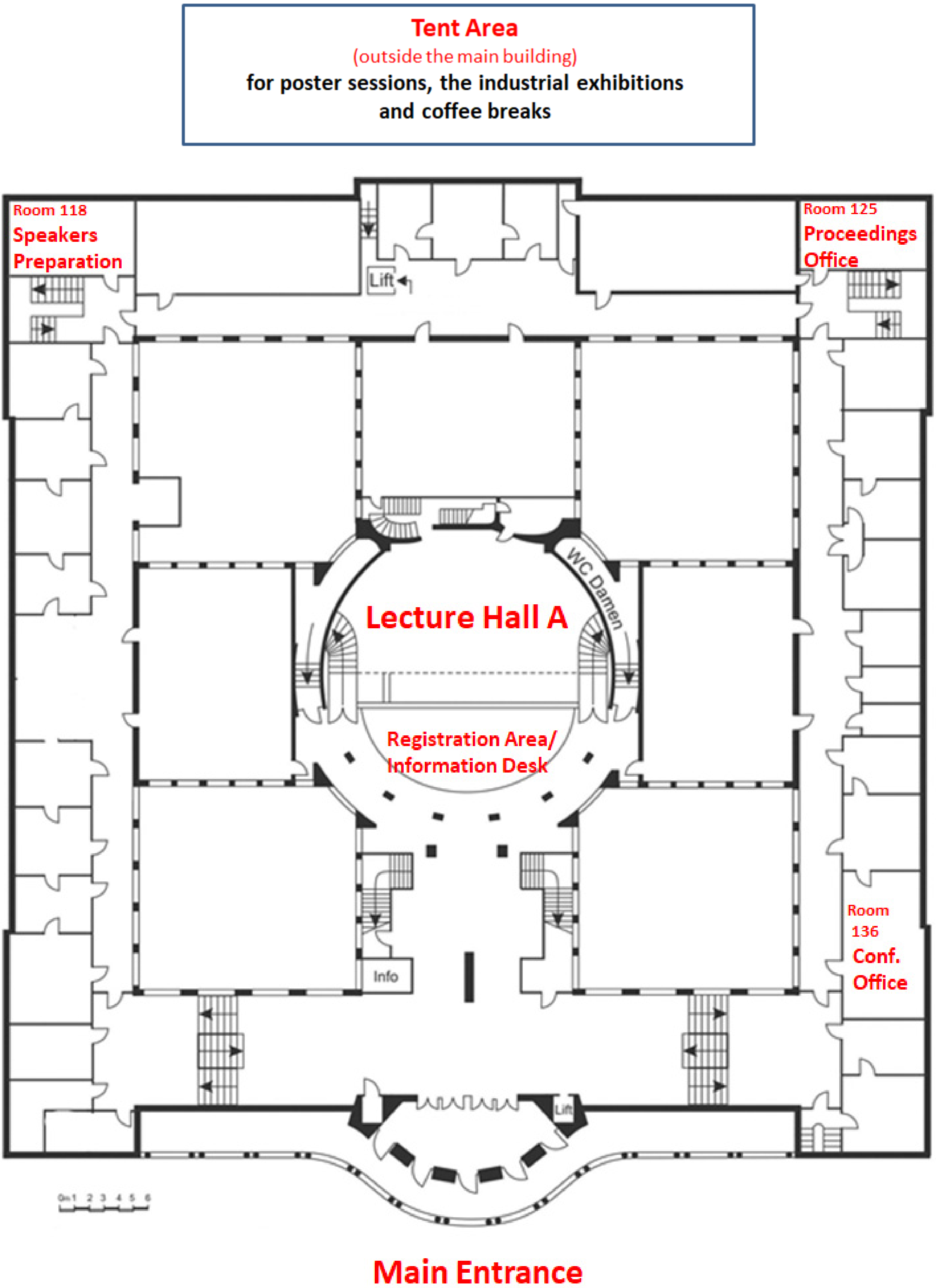
The drive will take 20 to 30 min. and the rate can be up to 35 €, depending on the traffic.

Transportation to DESY (on Friday, August 30th)

Take suburban line S1 to station Othmarschen. We will provide bus transfers from the train station in Othmarschen to DESY on Friday morning at around 08:30. You can also use the public bus #3 to get to the DESY main entrance.

Conference Venue Layout

The presentations and the tutorials will take place in Lecture Hall A at the University's main building. The location of the conference secretariat, the proceedings office and the speaker's preparation room are labelled as well. After entering the main entrance you will find straight ahead the registration area. Outside the main building is the tent area for the poster sessions, the industrial exhibitions and for the coffee breaks.



Useful Information about Hamburg

Security & Insurance
Participants are asked not to leave their belongings unattended and to wear their conference badges at all times on the conference site and at all social events.

The conference organizers cannot accept liability for medical, travel or personal insurance. Delegates are strongly recommended to arrange their own personal insurance.

Currency
The German currency is Euro (€). Exchange facilities are available at the airport, main train stations and exchange agencies.

Payment
It is still very popular to pay cash. Cards are not accepted everywhere.

Electricity
Electricity in Germany is 230 Volts, alternating at 50 cycles per second. If you travel to Germany with a device that does not accept 230 Volts at 50 Hertz, you will need a voltage converter.

Drinking water quality
The drinking water quality in Hamburg is excellent. Tap water can be used without any restrictions.

Weather in Hamburg
Frequent changes of weather make forecasting difficult. To be on the safe side, be sure to bring a sweater and wet weather clothing with you.

Finding a taxi
Official taxi stands are located at Hamburg Airport, all train stations and at popular shopping, business and tourist locations around the city. It’s also possible to hail a taxi on the street.

Tipping
Tipping in restaurants and bars is generally at 5-10%. Tipping taxi drivers is also a common practice.

Hours of Business
Most shops in Germany are open Monday to Saturday from 10:00 until 20:00.

Registration & Information Desk

Registration

Registration is open from 8:00 to 10:00 on Monday 26th August and will take place in the foyer of the Hamburg University Main Building.
From Tuesday to Thursday during the conference week it is possible to register at the conference office in room 136.

Conference Bag

Upon registering, you will receive your personal conference bag which comprises your conference badge, an abstract booklet, a ticket for free public transportation in Hamburg (HVV Ticket) and other important items. The HVV Ticket will be valid throughout the conference week.

Please note: You will need the HVV Ticket (for free public transportation) to go to the DESY campus on Friday morning.

Conference Fee

If you have not already paid your fee prior to arriving at the conference, you will be able to do so on Monday morning at the Registration Desk.

Conference Office

The conference office is located in room 136 and will be open Monday to Thursday from 8:00 to 18:00 h.

Information Desk

An Information Desk is set up in the foyer of the University's Main Building at the registration area. The information desk opens throughout the conference as follows:

Monday	8:00 – 18:00
Tuesday	8:00 – 18:00
Wednesday	8:00 – 18:00
Thursday	8:00 – 18:00

WLAN Usage and WLAN Registration

A conference WLAN will be set up at the venue. A password is needed to enter the conference WLAN. Passwords will be supplied during registration or later at the conference information desk.

Eduroam is available on the university campus without restrictions.

Welcome Reception

Welcome Reception (Monday, August 26, 2019, 19:00 h, Location: Beach-Club Strand Pauli)
We invite all participants to join us for a welcome reception at Beach-Club Strand Pauli. This is one of the oldest beach clubs in Hamburg and thrills locals and tourists equally with its relaxed setting and spectacular views of the Hamburg harbour.
This is an outdoor location, so please dress casually and according to the weather. Be sure to wear proper footwear for walking a short distance in sand.

Drinks and barbecue will be offered.

Please bring your badge as this will serve as the entrance ticket.

There are several options to get to the location:

1) Take a 45 minute walk through the famous city center park 'Planten und Blomen' and a stretch of the Reeperbahn - see attached map.

2) Walk to Dammtor and take **S-Bahn S21 direction Aumuehle and exit at Hauptbahnhof (central station)**, change platforms (you have to go up the stairs and down to the opposite platform) and take **S-Bahn S3 direction Altona and exit at Landungsbrücken**. From here you have to walk about 500 m; exit the station in direction 'Landungsbrücken', cross the street using the pedestrian bridge and walk along the waterfront towards West (right turn).

3) Walk 10 minutes to Stephansplatz and take **Bus 112 direction Neumuehlen and exit at St. Pauli Hafenstraße** directly opposite of the location.

4) Persons with limited mobility please contact the conference organizers.

The event is open ended. You can easily take public transportation (www.hvv.de/en) to get back to your hotel.

Address: Beach-Club StrandPauli
Hafenstraße 89
Hamburg

Please see the map on the next page for details:

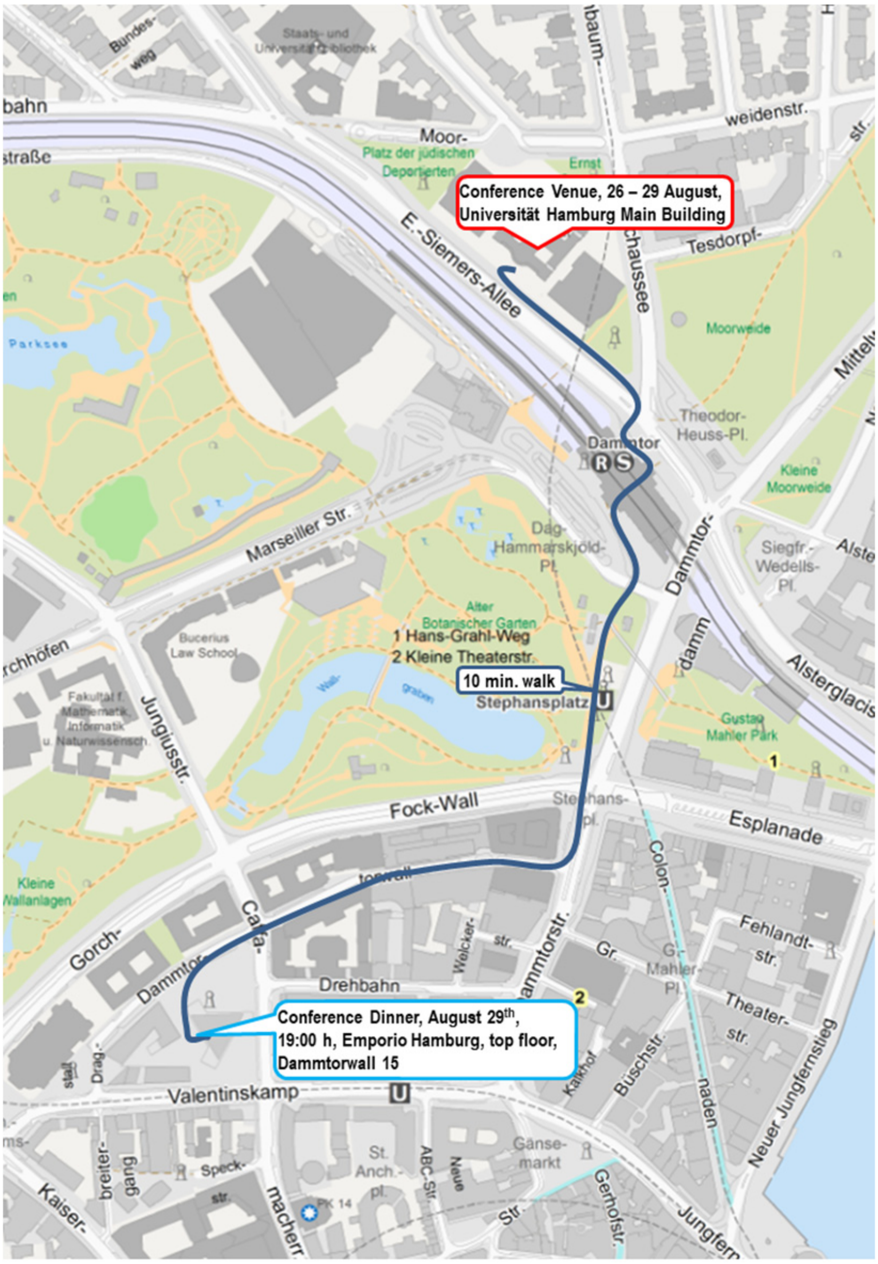
How to get from the conference venue to the reception:

https://geoportal-hamburg.de/geoportal/geo-online/

Conference Dinner

Conference Dinner (Thursday, August 29th, 19:00 h, Emporio Tower, top floor)
The Conference Dinner will take place on Thursday 29th August at 19:00 at the Emporio Tower.
This 90 m high building with 23 floors offers spectacular views over the city.
The Emporio Tower is located in a short walking distance from the conference venue. Please see the map below.
First and second course will be served at the table. Please indicate meat or veggie preferences upon registration.
A welcome address, the invitation to FEL2021 and the announcement for FEL2023 will be given from the stage in the bar area, followed by the announcement of the 2019 FEL Prize and Young Investigator Prize Winners.
Further discussions with your colleagues are possible over a desert buffet and live music.
Please bring your badge as this will serve as the entrance ticket.

Address:
Emporio Hamburg
Dammtorwall 15
20355 Hamburg



https://geoportal-hamburg.de/geoportal/geo-online/

Sponsors & Student Grants

20 students from all over the world have been selected for student grants. We would like to acknowledge and thank the following institutes for their student support:

- Elettra Sincrotrone Trieste
- MAX IV
- Pohang Accelerator Laboratory
- DESY
- European XFEL

Student Grant Committee
Marie-Emanuelle Couprie, Synchroton SOLEIL, Saint-Aubin
John Galayda, SLAC, Stanford
Jörg Rossbach (**Chair**), Universität Hamburg
Oleg A. Shevchenko, BINP, Novosibirsk
Zhentang Zhao, SINAP, Shanghai

Industrial Exhibition & List of Exhibitors

The industrial exhibition will be held from Tuesday through Thursday in a tent outside the University's Main Building. An overview plan with booth numbers will be displayed at the entrance of the tent.

Exhibition hours:

Tuesday	9:00 – 18:00
Wednesday	9:00 – 18:00
Thursday	9:00 – 18:00

List of exhibitors:

Company Name	Company Logo
Agilent Technologies Sales & Services GmbH & Co. KG	
Allectra Limited	
attocube systems AG	
CRYOPHYSICS GmbH	
Cycle GmbH	
ess Mikromechanik GmbH	
FuG Elektronik GmbH	
GLOBES	

Goodfellow	
Hositrad	
incoatec GmbH	
Inprentus	
Instrumentation Technologies, d.o.o.	
KYMA	
Luvata Pori Oy	
MicroTCA Technology Lab (A Helmholtz Innovation Lab)	
Microwave Amps Ltd	
OWIS GmbH	
Pfeiffer Vacuum GmbH	
Physik Instrumente (PI) GmbH & Co. KG	

Phytron GmbH	
PINK GmbH Vakuumtechnik	
R&K Company Limited	
SAES Getters S.p.A.	
Schulz-Electronic GmbH	
Shanghai ShuoSong Electronic Technology Co., Ltd.	
SmarAct GmbH	
Struck Innovative Systeme GmbH	
Vacuum FAB srl	
W-IE-NE-R Power Electronics GmbH	

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Lab Visits

We will offer several laboratory tours on Friday, August 30th, 2019.

You have the opportunity to visit either the FLASH experimental hall, the European XFEL accelerator or the European XFEL experimental hall after the morning session (tours last until about 14:30 h).

In case you are interested in visiting both European XFEL sites (accelerator and experimental hall) you should plan to stay until late afternoon. The last tour will finish at about 17:00 h.

You will be able to sign up for the tours during the conference. Places are limited.
A bus transfer between DESY and the European XFEL Campus as well as to the local train station Othmarschen, serving the train line S1, will be provided.

The schedule will allow for lunch on either the DESY or European XFEL site.

Proceedings & Proceedings Office

A pre-press release of papers and slides will be available right after the conference on the FEL2019 website: https://www.fel2019.org/

The final FEL'19 conference proceedings will be published on the JACoW website: https://www.jacow.org/Main/Proceedings?sel=FEL

Proceedings Office

In case there is a major problem with the paper the author must contact the Information Desk to arrange to see an Editor for help.

The Proceedings Office is located in Room 125.

Proceedings Office hours:

Monday	8:00 – 18:30
Tuesday	8:30 – 18:30
Wednesday	8:30 – 18:30
Thursday	8:30 – 17:30

Authors are requested to check on the status of their submitted paper by first consulting the electronic dotting board located in the foyer or by logging in to their JACoW FEL'19 SPMS account: https://oraweb.cern.ch/pls/fel2019/profile.html

JACoW Editorial Team

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Dong-Eon Kim (PAL/POSTECH, Korea)
Natalia Juszka (CERN, Switzerland)
Michaela Marx (DESY, **Editor-in-Chief**)
Raphael Müller (GSI, Germany)
John Poole (Pioneer Editor and founding member of JACoW, UK)
Ruth Rudolph (DESY, Germany)
Jens Völker (HZB, Germany)
Volker Schaa (GSI, Germany)

Oral Presentations

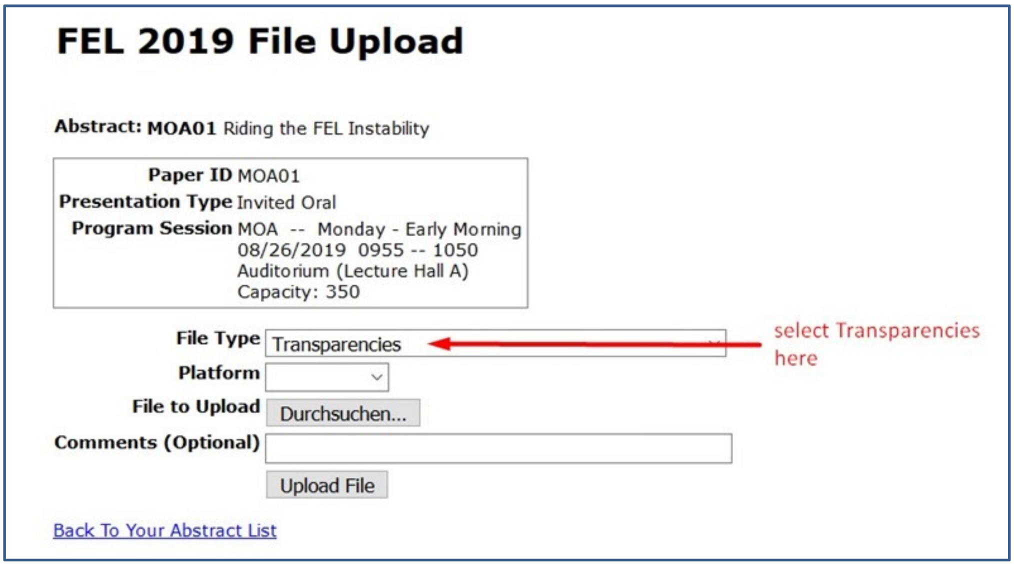
Oral Presentations
Oral presentations will take place in Lecture Hall A (Hörsaal A).

Invited talks are 25 + 5 minutes (presentation + discussion)
Contributed talks are 10 + 5 minutes (presentation + discussion)
Exceptions:
The "First Lasing Talks" on Monday Morning are scheduled for 5 minutes each; the memorial talk is 15 minutes, the FEL prize talks will last 20 minutes.

A speaker preparation room is available where speakers can preview and check their presentations for correct font embedding, movies, etc.

Speaker preparation office hours (Room 118)
Monday 26 August: 8:00 – 17:00
Tuesday 27 August to Thursday 29 August: 08:00 – 17:30

Please note: Speakers must upload their talks to the SPMS at least 24 hours in advance of their presentations, https://oraweb.cern.ch/pls/fel2019/profile.html



Example: How to upload a presentation to the JACoW database (SPMS).

All speakers must give their presentations from the computer set up in the auditorium, individual laptops cannot be accepted. We will provide a Windows laptop with Microsoft Office.

We accept PowerPoint presentations as well as PDF slides files.

In case the slides were prepared on a Macintosh computer please convert the presentation to PDF and make sure that all fonts are embedded (it's a Save Option).

Poster Sessions

Poster presentations are scheduled for Tuesday, Wednesday and Thursday after lunch, **from 14:15 to 15:45**, in the tent outside the main building.

Each poster board will be labelled with the appropriate paper code for easy detection. Poster pins will be supplied.

Poster Size

The poster format will be the ISO paper size of A0 Portrait.
ISO A0 dimensions are 841 mm wide x 1189 mm high or 33.1 inches wide by 46.8 inches high.

Poster Rules

Any paper not presented at the conference will be excluded from the Proceedings. Furthermore, the Scientific Program Committee reserves the right to reject publication of papers that were not properly presented in the poster sessions. Posters should be manned for at least one hour.

Poster Session Topics (Classifications)

Tuesday Poster Session - TUP
FEL Theory, SASE FEL, Seeded FEL, and FEL Oscillators and Long Wavelengths FEL

Wednesday Poster Session - WEP
Electron Sources, Electron Diagnostics, Timing, Synchronization & Controls,
and Photon Beamline Instrumentations and Undulators

Thursday Poster Session - THP
FEL Applications, Electron Beam Dynamics, Novel Concepts and Techniques,
and Status of Projects and Facilities

Tutorials

As part of an educational program for those new to the field of FELs, there will be two 60 minutes lectures scheduled for Tuesday and Wednesday, from 18:00 to 19:00.
The tutorial lectures will be given by Avraham Gover and Harald Sinn.

Tuesday, 27 August 2019, 18:00 – 19:00 h
Title: Coherent Spontaneous Superradiance and Stimulated-Superradiant Emission of Bunched Electron Beams
Speaker: Avraham Gover, University of Tel-Aviv, Tel-Aviv

Wednesday, 28 August 2019, 18:00 – 19:00 h
Title: Photon Transport Beamline Design
Speaker: Harald Sinn, EuXFEL, Hamburg

Scientific Program

Monday, August 26th (Location: Lecture Hall A)

Opening, Memorial Talk & First Lasing (Session MOA)

10:00 – 11:30, Chairs: Winni Decking & Harald Sinn

10:00 Opening of FEL2019
10:25 **Memorial Talk**: "Riding the FEL Instability", Giuseppe Dattoli (ENEA C.R. Frascati)
First Lasing Talks:
10:40 "First Lasing of a Free Electron Laser in the Soft X-Ray Spectral Range with Echo Enabled Harmonic Generation", Enrico Allaria (Elettra-Sincrotrone Trieste)
10:45 "First Lasing at the CAEP THz FEL Facility", Peng Li (CAEP/IAE)
10:50 "First Lasing at the SASE2 and SASE3 FELs of European XFEL", Matthias Scholz (DESY)
10:55 "First Lasing at SXFEL", Bo Liu (SARI-CAS)
11:00 "Commissioning of CW FEL Amplifier for Coherent Electron Cooler", Vladimir Litvinenko (BNL)
11:05 "Commissioning Status of FELiChEM, an IR-FEL User Facility in China", Heting Li (USTC/NSRL)

Coffee Break (11:30 – 12:00)

Status of Projects and Facilities 1 (Session MOB)

12:00 – 13:00, Chair: Siegfried Schreiber

12:00 **Invited:** "Operation Status and Future Perspective of Warm XFEL", Hitoshi Tanaka (RIKEN SPring-8 Center)
12:30 **Invited:** "Overview on Future Continuous Wave X-Ray Free Electron Lasers", Hans Weise (DESY)

Lunch Break (13:00 – 14:30)

FEL Prize Talks (Session MOC)

14:30 – 16:00, Chair: Dong Wang

14:30 "Regenerative Amplifier FEL - from IR to X-Rays", Dinh C. Nguyen (LANL)
14:50 "Microbunching Instability and Laser Heater Usage in Seeded Free-Electron Lasers", Eléonore Roussel (PhLAM/CERLA)
15:10 "Laser Heater Impact on the Performances of Seeded High Gain FELs", Eugenio Ferrari (PSI)
15:30 "Accelerator Challenges for XFELs with Very High X-Ray Energies", Bruce Carlsten (LANL)

Coffee Break (15:50 – 16:15)

FEL Theory (Session MOD)

16:15 – 17:45, Chair: Juhao Wu

16:15 **Invited:** "Physics of Post-Saturation Tapered FEL Towards Single-Frequency Terawatt Output Power", Cheng-Ying Tsai (HUST, Wuhan)
16:45 **Invited:** "Microbunch Rotation and Coherent Undulator Radiation from a Kicked Electron Beam", James MacArthur (SLAC)
17:15 "Hanbury Brown and Twiss Interferometry at XFEL Sources", Ivan Vartaniants (DESY)
17:30 "Post-Saturation Dynamics of a Superradiant Spike in a Free-Electron Laser Amplifier", Xi Yang (BNL)

Scientific Program

Tuesday, August 27th (Location: Lecture Hall A)

SASE FEL (Session TUA)

09:00 – 10:30, Chair: Eduard Prat

09:00 **Invited:** "Parallel Operation of SASE1 and SASE3 at European XFEL", Shan Liu (DESY)
09:30 **Invited:** "Two-Pulse Schemes in Soft and Hard X-Ray FELs: Robustness Analysis of State-of-the-Art Solutions", Alberto Lutman (SLAC)
10:00 "Generation of Sub-Femtosecond X-Ray Pulses at SwissFEL", Alexander Malyzhenkov (PSI)
10:15 "Harmonic Lasing Experiment at the European XFEL", Evgeny Schneidmiller (DESY)

Coffee Break (10:30 – 11:00)

Seeded FEL (Session TUB)

11:00 – 12:45, Chair: Giovanni De Ninno

11:00 **Invited:** "Echo-Enabled Harmonic Generation Lasing of the FERMI FEL in the Soft X-Ray Spectral Region", Primoz Rebernik Ribič (Elettra-Sincrotrone Trieste)
11:30 **Invited:** "Reflection Self-Seeding at SACLA", Toru Hara (RIKEN SPring-8 Center)
12:00 **Invited:** "Hard X-Ray Self-Seeding at PAL-XFEL", Chang-Ki Min (PAL)
12:30 "Generation and Measurement of Intense Few-Femtosecond Superradiant Soft X-Ray Free Electron Laser Pulses", Simone Spampinati (Elettra-Sincrotrone Trieste)

Lunch Break (12:45 – 14:15)

Poster Session 1 (Session TUP)

14:15 – 15:45

Topics: FEL Theory, SASE FEL, Seeded FEL, FEL Oscillators and Long Wavelengths FEL

Coffee Break (15:45 – 16:15)

FEL Oscillators and Long Wavelengths FEL (Session TUD)

16:15 – 17:45, Chair: Oleg Shevchenko

16:15 **Invited:** "Generating Orbital Angular Momentum Beams in an FEL Oscillator", Ying K. Wu (FEL/Duke University, Durham, North Carolina)
16:45 **Invited:** "Application of Infrared FEL Oscillators for Producing Isolated Attosecond X-Ray Pulses via High-Harmonic Generation in Rare Gases", Ryoichi Hajima (QST, Tokai)
17:15 "Fine and Hyperfine Structure of FEL Emission Spectra", Vitaly Kubarev (BINP SB RAS, Novosibirsk)
17:30 "Cavity-Based Free-Electron Laser Research and Development: A Joint Argonne National Laboratory and SLAC National Laboratory Collaboration", Gabriel Marcus (SLAC)

Coffee Break (17:45 – 18:00)

Tutorial

18:00 – 19:00, Chair: Gianluca Geloni

18:00 "Coherent Spontaneous Superradiance and Stimulated-Superradiant Emission of Bunched Electron Beams", Avraham Gover (University of Tel-Aviv)

Scientific Program

Wednesday, August 28th (Location: Lecture Hall A)

Electron Sources (Session WEA)

09:00 – 10:30, Chair: Bruce Carlsten

09:00 **Invited:** "Overview on CW RF Gun Developments for Short Wavelength FELs", Houjun Qian (DESY Zeuthen)
09:30 **Invited:** "State-of-the-Art Photocathodes and New Developments", Nathan Moody (LANL)
10:00 "Emittance Budget in the Transition Regime Between Linear Emission and Space Charge Dominated Photoemission", Ye Chen (DESY Zeuthen)
10:15 "Growing and Characterization of Cs2Te Photocatodes with Different Thicknesses at INFN LASA", Laura Monaco (INFN/LASA)

Coffee Break (10:30 – 11:00)

Electron Diagnostics, Timing, Synchronization, and Controls (Session WEB)

11:00 – 12:45, Chair: Alex Lumpkin

11:00 **Invited:** "Identification and Mitigation of Smoke-Ring Effects in Scintillator-Based Electron Beam Images at the European XFEL", Gero Kube (DESY)
11:30 **Invited:** "Wire-Scanners with Sub-Micrometer Resolution: Developments and Measurements", Gian Luca Orlandi (PSI)
12:00 **Invited: "**Application of Machine Learning to Beam Diagnostics", Elena Fol (CERN)
12:30 "Few-Femtosecond Facility-Wide Synchronization of the European XFEL", Sebastian Schulz (DESY)

Lunch Break (12:45 – 14:15)

Poster Session 2 (Session WEP)

14:15 – 15:45

Topics: Electron Sources, Electron Diagnostics, Timing, Synchronization, and Controls, Photon Beamline Instrumentation & Undulators, FEL Applications

Coffee Break (15:45 – 16:15)

Photon Beamline Instrumentation & Undulators (Session WED)

16:15 – 17:45, Chairs: Jan Grünert and Gianluca Geloni

16:15 **Invited:** "Experience with Short-Period, Small Gap Undulators at the SwissFEL Aramis Beamline", Thomas Schmidt (PSI)
16:45 **Invited:** "Absorbed Radiation Doses on the European XFEL Undulator Systems During Early User Experiments", Frederik Wolff-Fabris (EuXFEL)
17:15 "Pulse Resolved Photon Diagnostics at MHz Repetition Rates", Jan Grünert (EuXFEL)
17:30 "Undulator Adjustment with the K-Monochromator System at the European XFEL", Wolfgang Freund (EuXFEL)

Coffee Break (17:45 – 18:00)

Tutorial

18:00 – 19:00, Chair: Alex Lumpkin

18:00 "Photon Transport Beamline Design“, Haral Sinn (EuXFEL)

Scientific Program

Thursday, August 29th (Location: Lecture Hall A)

FEL Applications (Session THA)

09:00 – 10:45, Chair: Young Uk Jeong

09:00 **Invited:** "Serial Femtosecond Crystallography at MHz XFELs", Marie Luise Grünbein (Max Planck Institute for Medical Research, Heidelberg)
09:30 **Invited:** "Searching for the Hypothesized Liquid-Liquid Critical Point in Supercooled Water with X-Ray Free Electron Laser", Kyung Hwan Kim (POSTECH)
10:15 **Invited:** "IR-FEL Project at the cERL and Future EUV-FEL Lithography ", Ryukou Kato (KEK)
10:30 "Ultrafast Magnetization Dynamics at the Low-Fluence Limit Supported by External Magnetic Fields", Matthias Riepp (DESY)

Coffee Break (10:45 – 11:15)

Electron Beam Dynamics (Session THB)

11:15 – 12:45, Chair: Simona Bettoni

11:15 **Invited:** "Using an E-SASE Compression to Suppress Microbunch Instability and Resistive-Wall Wake Effects", Petr Anisimov (LANL)
11:45 **Invited:** "Understanding 1-D to 3-D Coherent Synchrotron Radiation Effects", Alexander Brynes (STFC/DL/ASTeC)
12:15 "Emittance Measurements and Minimization at SwissFEL", Philipp Dijkstal (PSI)
12:30 "Longitudinal Phase Space Study on Injector Beam of High Repetition Rate FEL", Qiang Gu (SSRF)

Lunch Break (12:45 – 14:15)

Poster Session 3 (Session THP)

14:15 – 15:45

Topics: Electron Beam Dynamics, Novel Concepts and Techniques, Status of Projects and Facilities

Coffee Break (15:45 – 16:15)

Novel Concepts and Techniques (Session THD)

16:15 – 18:00, Chair: Sandra Biedron

16:15 **Invited:** "From Femtosecond to Attosecond Coherent Undulator Pulses", Vitaliy Goryashko (Uppsala University)
16:45 **Invited:** "Attosecond Pulses from Enhanced SASE at LCLS", Agostino Marinelli (SLAC)
17:15 **Invited:** "FEL Optimization: From Model-Free to Model-Dependent Approaches and ML Prospects", Sergey Tomin (EuXFEL)
17:30 "A Novel Optical Undulator Using Array of Pulse-Front Tilted Laser Beams", Weihao Liu (USTC/NSRL)

Break (18:00 – 19:00)

19:00 Conference Dinner

Scientific Program

Friday, August 30th (New Location: DESY campus, main auditorium)

Status of Projects and Facilities 2 (Session FRA)

09:00 – 11:30, Chair: Luca Gianessi

09:00 **Invited:** “Operation at the European XFEL Facility”, Dirk Noelle (DESY)
09:30 **Invited:** “LCLS-II - Status and Upgrades”, Axel Brachmann (SLAC)
10:00 **Invited:** “FLASH - Status and Upgrades”, Juliane Roensch-Schulenburg (DESY)
10:30 **Invited:** “Status of SXFEL Test and User Facilities”, Zhentang Zhao (SSRF)
11:00 Concluding Remarks, Introduction Lab Visits

Coffee Break (11:30 – 12:00)

Lab Visits (EuXFEL, FLASH)

12:00 – 17:00

17:00 End of the Conference

Table of Abstracts

26-Aug-19 10:25 – 11:30 Auditorium (Lecture Hall A)

MOA — Monday - Early Morning

Chair: W. Decking (DESY)

MOA01 10:25 15 **Riding the FEL Instability**

G. Dattoli (ENEA C.R. Frascati) C. Pellegrini (SLAC)

The Free Electron Laser (FEL) operation, like that of any Free Electron source of coherent radiation, is associated with the onset of an instability. The interplay between the FEL and other instabilities, affecting the beam, is one of the interesting aspects of the associated dynamics. It involves issues of practical interest (Renieri Limit in Storage Ring FELs, suppression of instabilities like saw-tooth and synchrotron…). The paper reviews these problems and offers an overview of the scientific contribution of Alberto Renieri to the FEL from this perspective.

MOA02 10:40 5 **First Lasing of a Free Electron Laser in the Soft X-Ray Spectral Range with Echo Enabled Harmonic Generation**

***E. Allaria**, A. Abrami, L. Badano, M. Bossi, N. Bruchon, F. Capotondi, D. Castronovo, M. Cautero, P. Cinquegrana, M. Coreno, I. Cudin, M.B. Danailov, G. De Ninno, A.A. Demidovich, S. Di Mitri, B. Diviacco, W.M. Fawley, M. Ferianis, L. Foglia, G. Gaio, F. Giacuzzo, L. Giannessi, F. Iazzourene, G. Kurdi, M. Lonza, N. Mahne, M. Malvestuto, M. Manfredda, C. Masciovecchio, N.S. Mirian, I. Nikolov, G. Penco, E. Principi, L. Raimondi, P. Rebernik Ribič, R. Sauro, C. Scafuri, P. Sigalotti, S. Spampinati, C. Spezzani, L. Sturari, M. Svandrlik, M. Trovò, M. Veronese, D. Vivoda, M. Zaccaria, D. Zangrando, M. Zangrando, S. dr. Grulja (Elettra-Sincrotrone Trieste S.C.p.A.) H.-H. Braun, E. Ferrari, E. Prat, S. Reiche (PSI) N. Bruchon (University of Trieste) M. Coreno (CNR-ISM) M.-E. Couprie, A. Ghaith (SOLEIL) G. De Ninno (University of Nova Gorica) C. Feng (SARI-CAS) F. Frassetto, L.P. Poletto (LUXOR) D. Garzella (CEA) V. Grattoni (DESY) E. Hemsing (SLAC) P. Miotti (CNR-IFN) G. Penn (LBNL) M.A. Pop (MAX IV Laboratory, Lund University) E. Roussel (PhLAM/CERCLA) T. Tanikawa (EuXFEL) D. Xiang (Shanghai Jiao Tong University)*

We report on the successful operation of a Free Electron Laser in the Echo Enabled Harmonic Generation (EEHG) scheme. The experiment required a modification of the FERMI FEL-2 undulator line which in normal operation uses two stages of high-gain harmonic generation separated by a delay line. In addition to a new seed laser, the dispersion in the delay-line was increased, the second stage modulator changed and a new manipulator installed in the delay-line chicane hosting additional diagnostic components. With the modified setup we have demonstrated the first evidence of exponential gain in a free electron laser operated in EEHG at wavelengths as short as 5 nm.

MOA03 10:45 5 **First Lasing at the CAEP THz FEL Facility**

***M. Li**, P. Li, D. Wu (CAEP/IAE)*

China Academy of Engineering Physics terahertz free electron laser (CAEP THz FEL, CTFEL) is the first THz FEL user facility in China, which was an oscillator type FEL. This THz FEL facility consists of a GaAs photocathode high-voltage DC gun, a superconducting RF linac, a planar undulator and a quasi-concentric optical resonator. The terahertz laser's frequency is continuous adjustable from 2 THz to 4 THz. The average power is more than 10 W and the micro-pulse power is more than 0.5 MW. In this paper, the specific parameters and operation status of CTFEL are presented. Finally, some user experiments are introduced briefly.

MOA04 10:50 5 **First Lasing at the SASE2 and SASE3 FELs of European XFEL**

***M. Scholz** (DESY)*

The European XFEL includes three Free Electron Lasers. We report on the first lasing at the soft X-ray SASE FEL SASE3 in February 2018 and at the second hard X-Ray SASE FEL SASE2 in May 2018.

MOA05 10:55 5 **First Lasing at SXFEL**

***Z.T. Zhao**, M. Gu, Q. Gu, Y.B. Leng (SSRF) H.X. Deng, B. Liu, D. Wang (SARI-CAS) G.P. Fang, L. Yin, M. Zhang (SINAP)*

Shanghai soft X-ray free-electron laser (SXFEL) started its construction in December of 2014. After years of effort, first lasing at 8.8 nm with designed cascading mode is finally achieved in 2019. The commissioning progress and recent results will be reported.

MOA06 11:00 5 **Commissioning of CW FEL Amplifier for Coherent Electron Cooler**

***V. Litvinenko** (BNL)*

V.N.Litvinenko for CeC team An FEL-based Coherent electron Cooling (CeC) has a potential to significantly boosting luminosity of high-energy, high-intensity hadron-hadron and electron-hadron colliders. In a CeC system, a hadron beam interaction with a cooling electron beam is amplified using a high gain FEL. In contrast with the typical FEL applications, the CeC needs a linear amplifier, e.g. the FEL has to be operating in a linear regime without saturation. The CeC FEL is comprised of three helical wigglers and is driven by 14.5 MeV electron beam from CW SRF accelerator. In this talk we present results of successful commissioning of such FEL amplifier.

MOA07 11:05 5 **Commissioning Status of FELiChEM, an IR-FEL User Facility in China**

***H.T. Li**, Q.K. Jia, L. Wang, S.C. Zhang (USTC/NSRL)*

An IR-FEL user facility named FELiChEM has been constructed in University of Science and Technology of China (USTC), whose core device is an FEL oscillator generating middle-infrared and far-infrared laser and covering the spectral range of 2.5-200 μm. The commissioning of the machine was started from August, 2018. In this paper we present the commissioning status and some special issues.

26-Aug-19 12:00 – 13:00 Auditorium (Lecture Hall A)

MOB — Monday - Late Morning

Chair: S. Schreiber (DESY)

MOB01 12:00 30

Operation Status and Future Perspective of Warm XFEL

H. Tanaka (RIKEN SPring-8 Center)

The world first XFEL facility, LCLS adopted a warm (normal conducting) S-band RF technology to constantly provide high quality electron beams with high energy for generating stable SASE-based XFELs. Following the success of LCLS, SACLA, PAL-XFEL and SwissFEL based on the warm RF technologies of S- or C-bands were constructed and have started their user operations or test experiments via the beam-commissioning phase. These warm XFEL facilities have developed various advanced FEL schemes making high performance XFELs available for user experiments. They have been continuously upgrading the operations for expanding experimental opportunities and potentiality. This talk will overview the current operational status of warm XFEL facilities and present future perspectives compared with cold (super-conducting) XFEL facilities.

MOB02 12:30 30

Overview on Future Continuous Wave X-Ray Free Electron Lasers

H. Weise *(DESY)*

FELs based on superconducting accelerators offer a photon beam time structure being flexible in pulse pattern, with the electron bunch properties tailored to effectively meet user requirements. While DESY's long time operated FLASH facility as well as the in 2017 commissioned European XFEL in the Hamburg region, Germany, are operated in pulsed mode with bunch trains of up to 600 µs and bunch repetition rates of up to 4.5 MHz, new facilities aim for continuous wave (cw) RF operation allowing bunch repetition rates of typically 100 kHz to 1 MHz. The used accelerator modules are still using the so-called TESLA technology. Minor but essential modifications in the accelerating structure design bring the cryogenic load to a reasonable and acceptable level. The upcoming LCLS-II, being under construction at SLAC, U.S., uses so-called Nitrogen doped accelerating structures. The recently started SHINE project at Shanghai, China, will adopt similar ideas. For a possible European XFEL upgrade towards cw, also so-called large grain Niobium is an option. The presentation will give an overview about R&D towards the great future of X-ray FELs. Activities in all three regions will be described.

26-Aug-19 14:30 – 15:50	Auditorium (Lecture Hall A)

MOC — Monday - Early Afternoon

Chair: D. Wang (SINAP)

MOC01 14:30 20

Regenerative Amplifier FEL - from IR to X-Rays

D.C. Nguyen *(LANL)*

The RAFEL uses a small fraction of the radiation exiting a high-gain undulator as the seed for the next pass. For the IR RAFEL, we used a hole out-coupler to reflect an annular beam and demonstrated saturation in a few passes. We theorized the RAFEL output transformed from an annular to an on-axis beam due to optical guiding at high power. Since then, a number of researchers have considered RAFEL in the X-rays to achieve full temporal coherence in high-repetition-rate FELs. In the X-ray region, Bragg backscattering can be used to provide very high reflectivity for the XFELO. For the RAFEL, the reflectivity of Bragg backscattering may be lower as the sub-femtosecond X-ray spikes are too short to reach the steady-state Bragg condition. Similarly, a thin diamond (111) with thickness less than the extinction length can be used as the partially reflecting Bragg crystal to provide ~50% reflectivity within the ~10^{-5} spectral response curve, sufficiently high for the RAFEL with large single-pass gain in the X-rays to reach saturation. The transmitted radiation (~50%) through the partially reflecting Bragg crystal serves as the RAFEL coherent X-ray output.

MOC02 14:50 20

Microbunching Instability and Laser Heater Usage in Seeded Free-Electron Lasers

E. Roussel *(PhLAM/CERLA) E. Ferrari (PSI)*

Seeded FELs are tremendous coherent sources in the EUV and soft X-rays domain. They are driven by high-quality electron beams produced in linear accelerators. However, spatio-temporal instabilities can develop in the magnetic compressor chicanes degrading the beam quality. The so-called microbunching instability is a major limitation for the generation of coherent pulses in the X-ray domain. Laser-heater systems are nowadays routinely used to control the electron beam energy spread in order to dump this instability. In the last years, there have proven to be also a powerful device to influence the FEL amplification process. We present here several LH usages in FELs with specific examples achieved on seeded FELs such as improving the harmonic up-conversion process in HGHG seeded FEL, generating short FEL pulses or also producing multi-color FEL pulses. We also report on microbunching instability issues and its effect on FEL spectral quality with strategies to benefit from that. Direct observation of the microbunching level in the electron beam remains also an open challenge. Innovative strategies to measure the electron beam and potentially its microbunching will be presented.

MOC03 15:10 20

Laser Heater Impact on the Performances of Seeded High Gain FELs

E. Ferrari *(PSI) E. Roussel (PhLAM/CERCLA)*

Laser-heater systems have been demonstrated to be an important component for the accelerators that drive high gain free electron laser (FEL) facilities, dramatically improving the performance of such lightsources. They are nowadays routinely used in most of the operating FEL facilities around the world. The improvement is achieved by suppressing the longitudinal microbunching instability via a controllable increase in the slice energy spread. The system has also been extensively used to manipulate the properties of the electron beam e.g., to produce short pulses of radiation, or for multicolor FEL generation. In this contribution we focus on the usage and impact of such system on a seeded FEL facility, with particular focus on the possibility of efficient generation of short wavelength radiation with unexpected power levels.

MOC04 15:30 20

Accelerator Challenges for XFELs with Very High X-Ray Energies

B.E. Carlsten *(LANL)*

Future X-ray Free-Electron Lasers (XFELs) will produce coherent X-rays with energies much greater than 20 keV, requiring electron beams with lower laboratory emittances and relative energy spreads than those in current XFELs. To satisfy this requirement, electron beam energies would need to be significantly higher than in current XFEL designs if conventional accelerator architectures are used, leading to increased construction and operation costs. To provide design margin for these future XFELs at the lowest possible electron beam energies, novel schemes may be employed to suppress or eliminate limitations introduced by coherent synchrotron radiation, undulator resistive wall wakes, the microbunch instability, and intrabeam scattering.

26-Aug-19 16:15 – 17:45 Auditorium (Lecture Hall A)

MOD — Monday - Late Afternoon

Chair: J. Wu (SLAC)

MOD01 16:15 30 **Physics of Post-Saturation Tapered FEL Towards Single-Frequency Terawatt Output Power**

C.-Y. Tsai *(HUST)*

TW-level output power of a single-pass high-gain x-ray FEL has recently attracted much attention. GW-level power can be achieved out of beneficial FEL instability. The remaining factor of 50 before reaching TW poses great challenges, including sustaining power growth and retaining spectral purity in the post-saturation regime. Post-saturation FEL physics involves the sideband instability, radiation diffraction, undulator tapering etc. In this talk I will introduce FEL sideband and diffraction effects, and give an estimate of individual effects to the overall performance. Undulator tapering is known an effective route to enhance power extraction efficiency. We recently proposed an efficiency-enhancement scheme based on preserving the longitudinal beam phase space, which ensures trapping of resonant particles in the ponderomotive bucket and meanwhile takes advantage of the increasing radiation amplitude to precipitate the particle deceleration process. Analysis shows that the optimal power efficiency based on the proposed scheme, together with a prebunched beam, can be greatly improved within a relative short taper length and the sideband effects effectively suppressed.

MOD02 16:45 30 **Microbunch Rotation and Coherent Undulator Radiation from a Kicked Electron Beam**

J.P. MacArthur *(SLAC)*

Microbunches form perpendicular to the electron travel direction, and the conventional understanding is that they shear rather than rotate in response to a transverse kick, locking FEL facilities into a single-user operating mode. We show that microbunches rotate toward the new direction of travel if the electron beam is kicked and defocused. We provide evidence that microbunch rotation explains the unexpectedly large amount of off-axis radiation observed during experiments at the Linac Coherent Light Source. We demonstrate that LCLS can be multiplexed into at least three soft X-ray beams using this principle. Finally, we report on a more sophisticated scheme of offset quadrupoles that was used to produce two distinct hard X-ray spots at LCLS.

MOD03 17:15 15 **Hanbury Brown and Twiss Interferometry at XFEL Sources**

I. Vartaniants *(DESY)*

The invention of optical lasers led to a revolution in the field of optics as well as to the birth of quantum optics. The reasons were the unique statistical and coherence properties of lasers. Short-wavelength free-electron lasers (FELs) are sources of bright, coherent extreme-ultraviolet and X-ray radiation with pulse duration on the order of tens of femtoseconds and are presently considered to be laser sources at these energies. Hanbury Brown and Twiss (HBT) interferometry that is based on intensity correlations allows fast and comprehensive analysis of the FEL statistical properties. We demonstrate that self-amplified spontaneous emission (SASE) FELs are highly spatially coherent to the first-order, but despite their name, statistically behave as chaotic sources. HBT measurements performed at an externally seeded FEL FERMI showed that it behaves as a real laser-like source according to a Glauber definition.

MOD04 17:30 15 **Post-Saturation Dynamics of a Superradiant Spike in a Free-Electron Laser Amplifier**

X. Yang *(BNL) L. Giannessi (ENEA C.R. Frascati) L. Giannessi, N.S. Mirian (Elettra-Sincrotrone Trieste S.C.p.A.)*

The generation of a single X-ray isolated spike of radiation with peak power at multi-GW level and femtosecond temporal duration represents a unique opportunity in time resolved diffraction imaging of isolated molecules or non-periodic structures for acquiring single shot images before the Coulomb explosion of the sample takes place. Such a condition is met by an FEL operating in superradiant regime for the possibility of simultaneously reducing the pulse duration while increasing the peak power and the pulse energy. We study the dynamics of an isolated spike of radiation in superradiant regime. We show that conditions exist where the pulse moves with a group velocity larger than one and is followed by a pedestal resulting from a complex post-saturation dynamic. The tail is constituted by a train of sub-pulses with both transverse and longitudinal coherence and decaying amplitudes. We analyze the dynamical conditions leading to the formation of the main pulse and the tail. We study the correlation of the tail structure with the longitudinal phase space of the electrons and provide a recipe to partially suppress this tail.

TUA — Tuesday - Early Morning

Chair: E. Prat (PSI)

TUA01 09:00 30 **Parallel Operation of SASE1 and SASE3 at European XFEL**

S. Liu *(DESY)*

At European XFEL a hard X-Ray SASE FEL (SASE1) and a soft X-Ray SASE FEL (SASE3) are located in series in the same electron beamline. This configuration couples the operating conditions for both undulators and their subsequent user experiments in terms of SASE intensity and synchrotron radiation background. We will report on the operating experience and solutions that enable as independent as possible operation of both undulators.

TUA02 09:30 30 **Two-Pulse Schemes in Soft and Hard X-Ray FELs: Robustness Analysis of State-of-the-Art Solutions**

A.A. Lutman *(SLAC)*

Several X-ray two-pulse schemes have been developed to meet the increasing experimental requirements in terms of power, wavelength separation and delay control. For particular experiments, the wavelength or the delay applicability range limits the choice of the usable scheme to a single one. In other occasions multiple schemes can produce the desired X-ray beams and the choice of the used one falls on operation simplicity. An example are two-color beams in the soft X-rays produced with the fresh-slice schemes that can be enabled by different time-dependent orbit control or by transverse matching. The focus in this talk will be on the operation robustness, reliability and reproducibility for the different two-color schemes.

TUA03 10:00 15 **Generation of Sub-Femtosecond X-Ray Pulses at SwissFEL**

A. Malyzhenkov*, Y.P. Arbelo, S. Bettoni, P. Craievich, P. Dijkstal, E. Ferrari, P.N. Juranič, E. Prat, S. Reiche (PSI)*

We report on the first generation of sub-femtosecond hard X-ray FEL pulses at SwissFEL. A few microjoule pulses with a single spike in the frequency domain have been predicted by simulations and then experimentally demonstrated. Ultra-short X-ray pulses are produced by the electron bunch with a specially-tailored current profile and longitudinal phase space. This configuration is achieved by means of an optimized nonlinear compression. Two- and three-stage nonlinear compression schemes are compared in terms of FEL performance and stability. We also discuss different FEL lasing regimes that can be realized depending on the particular configuration of the electron beam and undulator settings.

TUA04 10:15 15 **Harmonic Lasing Experiment at the European XFEL**

E. Schneidmiller*, F. Brinker, W. Decking, D. Nölle, M.V. Yurkov, I. Zagorodnov (DESY) N. Gerasimova, J. Grünert, N.G. Kujala, J. Laksman, Y. Li, J. Liu, Th. Maltezopoulos, I. Petrov, L. Samoylova, S. Serkez, H. Sinn, F. Wolff-Fabris (EuXFEL)*

Harmonic lasing is an opportunity to extend the photon energy range of existing and planned X-ray FEL user facilities. Contrary to nonlinear harmonic generation, harmonic lasing can provide a much more intense, stable, and narrow-band FEL beam. Another interesting application is Harmonic Lasing Self-Seeding (HLSS) that allows to improve the longitudinal coherence and spectral power of a Self-Amplified Spontaneous Emission (SASE) FEL. We present recent results from the European XFEL where we successfully demonstrated operation of HLSS FEL in the Angstrom regime. This is an important milestone on the way towards harmonic lasing at the European XFEL in the ultra-hard X-ray range, up to 100 keV.

27-Aug-19 11:00 – 12:45 Auditorium (Lecture Hall A)

TUB — Tuesday - Late Morning

Chair: G. De Ninno (Elettra-Sincrotrone Trieste S.C.p.A.)

TUB01 11:00 30
Echo-Enabled Harmonic Generation Lasing of the FERMI FEL in the Soft X-Ray Spectral Region
P. Rebernik Ribič *(Elettra-Sincrotrone Trieste S.C.p.A.)*
The layout of the FERMI FEL-2 undulator line, normally operated in the two-stage high-gain harmonic generation (HGHG) configuration, was temporarily modified to allow running the FEL in the echo-enabled harmonic generation (EEHG) mode. The EEHG setup produced stable, intense and nearly fully coherent pulses at wavelengths as short as 5.9 nm (211 eV). Comparing the performance to the two-stage HGHG showed that EEHG gives significantly better spectra in terms of the central wavelength stability and bandwidth, especially at high harmonics, where electron-beam imperfections start to play a significant role. Observation of stable, narrowband, coherent emission down to 2.6 nm (474 eV) indicates the possibility to extend the lasing region to even shorter wavelengths.

TUB02 11:30 30
Reflection Self-Seeding at SACLA
I. Inoue, *T. Hara (RIKEN SPring-8 Center)*
XFEL are widely operated based on the self-amplified spontaneous emission (SASE) scheme, where spontaneous radiation originating from density modulations in the electron beam is amplified along periodic magnetic field in undulators. Although the SASE scheme effectively produces intense X-ray beams, the stochastic starting-up processes cause poor temporal coherence and a broad spectrum. To narrow the bandwidth while keeping high intensity, we have recently developed an efficient seeding scheme at SACLA, called reflection self-seeding; the SASE-XFEL beam in the first-half undulators is monochromatized via Bragg reflection of a silicon channel-cut crystal, and the monochromatic seed is amplified in the remaining undulators. By applying this scheme to SACLA, we succeeded in producing nearly Fourier-transform-limited XFEL pulses, corresponding to an increase of spectral brightness by a factor of six with respect to the SASE-XFEL. In this presentation, I will talk about the concept of the reflection self-seeding and technical details. Also, I will report on the current operation status and future perspectives of the reflection self-seeding at SACLA.

TUB03 12:00 30
Hard X-Ray Self-Seeding at PAL-XFEL
C.-K. Min, *M.H. Cho, H. Heo, H.-S. Kang, C. Kim, G. Kim, M.J. Kim, J.H. Ko, D.H. Na, I.H. Nam, B.G. Oh, S.Y. Rah, C.H. Shim, Y.J. Suh, H. Yang (PAL) K. Kim, D. Shu, Yu. Shvyd'ko (ANL)*
A hard X-ray self-seeding utilizing time-delayed forward Bragg diffracted photons from thin diamond crystals has been successfully commissioned in a broad spectral range (3.5~14.4 keV), and will be soon provided to user experiments. In the self-seeded mode, the spectral bandwidth is typically 0.2~0.5 eV FWHM in contrast to SASE mode, in which the spectral bandwidth is around 20 eV. This implies that the seeded FEL can be a single longitudinal mode laser since the number of longitudinal mode is 100~200 in the SASE operation. In this case, the photon number of filtered FEL is expected to be fluctuated 100% from the narrow bandwidth filtering out of random and spiky SASE spectra. We found that our energy stability of electron bunches (10^{-4}) do not degrade much the seeding performance and the large variation of the seeded FEL intensity will be from the seeding probability. The advantages of 30 um thin diamond crystal and diagnostic tool for the self-seeding will be also presented.

TUB04 12:30 15
Generation and Measurement of Intense Few-Femtosecond Superradiant Soft X-Ray Free Electron Laser Pulses
S. Spampinati, *E. Allaria, L. Badano, C. Callegari, G. De Ninno, M. Di Fraia, S. Di Mitri, L. Giannessi, N. Mahne, M. Manfredda, N.S. Mirian, G. Penco, O. Plekan, K.C. Prince, L. Raimondi, P. Rebernik Ribič, C. Spezzani, M. Trovò, M. Zangrando (Elettra-Sincrotrone Trieste S.C.p.A.) R. Feifel, R. Squibb (Uppsala University) T. Mazza (EuXFEL) X. Yang (BNL)*
Intense FEL VUV and soft X-ray pulses with a time duration of few fs allows to probe ultrafast, out-of equilibrium dynamics or to pump the sample driving new phase transitions in regimes where uniform heating is not depleted by secondary energy decay channels, such as Auger effect [Principi]. Most of the methods proposed to reduce the FEL pulse duration are based on a manipulation of longitudinal electron beam properties such as emittance, beam current, energy spread, trajectory or optical functions. We present an attractive alternative based on the exploitation of the FEL dynamic process itself, driving the FEL amplifier in saturation and superradiance in a cascade of undulators resonant at higher harmonics of an initial seed. At FERMI we have implemented for the first time a multistage superradiant cascade reaching EUV-soft X-ray wavelengths and producing high-power, stable, FEL pulses with a duration of about 5 fs. We report here the analysis of the configuration used and of the characterization of the radiation produced in this regime.

TUP — Tuesday Poster Session

TUP001 Extension of the PITZ Facility for a Proof-of-Principle Experiment on THz SASE FEL

***P. Boonpornprasert**, G.Z. Georgiev, G. Koss, M. Krasilnikov, X. Li, F. Müller, A. Oppelt, S. Philipp, H. Shaker, F. Stephan, T. Weilbach (DESY Zeuthen) Z.G. Amirkhanyan (CANDLE SRI)*

The Photo Injector Test Facility at DESY in Zeuthen (PITZ) has been proposed as a suitable facility for research and development of an accelerator-based THz source prototype for pump-probe experiments at the European XFEL. A proof-of-principle experiment to generate THz SASE FEL radiation by using an LCLS-I undulator driven by an electron bunch from the PITZ accelerator has been planned and studied. The undulator is foreseen to be installed downstream from the current PITZ accelerator, and an extension of the accelerator tunnel is necessary. Radiation shielding for the extended tunnel was designed, and construction works are finished. Design of the extended beamline is ongoing, not only for this experiment but also for other possible experiments. Components for the extended beamline, including magnets for beam transport, a chicane bunch compressor, electron beam diagnostics devices, and THz radiation diagnostics devices have been studied. An overview of these works will be presented in this paper.

TUP002 Progress in Preparing a Proof-of-Principle Experiment for THz SASE FEL at PITZ

***X. Li**, P. Boonpornprasert, Y. Chen, G.Z. Georgiev, J.D. Good, M. Groß, P.W. Huang, H. Huck, I.I. Isaev, C. Koschitzki, M. Krasilnikov, S. Lal, O. Lishilin, G. Loisch, D. Melkumyan, R. Niemczyk, A. Oppelt, H.J. Qian, H. Shaker, F. Stephan, G. Vashchenko (DESY Zeuthen)*

A proof-of-princle experiment for THz SASE FEL is undergoing at the Photo Injector Test facility at DESY in Zeuthen (PITZ), as a prototype THz source for pump-probe experiments at the European XFEL, which could potentially provide up to mJ/pulse THz radiation while maintaining the identical pulse train structure as the XFEL pulses. In the proof-of-principle experiment, the LCLS-I undulators will be installed to generate SASE radiation in the THz ranges of 3-5 THz from electron bunches of 16-22 MeV/c. One key design is to obtain the peak current of nearly 200 A from the heavily charged bunches of a few nC. In this paper, we report our simulation results on the optimization of the space charge dominated beam in the photo injector and the following transport line with two cathode laser setups. Experimental results based on a short Gaussian laser will also be discussed.

TUP003 Design of a Magnetic Bunch Compressor for the THz SASE FEL Proof-of-Principle Experiment at PITZ

***H. Shaker**, P. Boonpornprasert, G.Z. Georgiev, G. Koss, M. Krasilnikov, X. Li, A. Oppelt, S. Philipp, F. Stephan (DESY Zeuthen)*

For pump-probe experiments at the European XFEL, a THz source is required to produce intense THz pulses at the same repetition rate as the X-ray pulses from XFEL. Therefore, an accelerator-based THz source with identical electron source as European XFEL was suggested and proof-of-principle experiments utilizing an LCLS I undulator will be performed at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The main idea is to use a 4nC beam for maximum SASE radiation but to allow different radiation regimes a magnetic bunch compressor can be used. This helps e.g. to reduce the saturation length inside the undulator and also to study super-radiant THz radiation. In this paper a design of a chicane type magnetic bunch compressor using HERA corrector magnets is presented.

TUP004 A Superradiant THz Undulator Source for XFELs

***T. Tanikawa**, G. Geloni, S. Karabekyan, S. Serkez (EuXFEL) V.B. Asgekar (University of Pune) S. Casalbuoni (KIT) M. Gensch (Technische Universität Berlin) M. Gensch (DLR) S. Kovalev (HZDR)*

The European XFEL has successfully achieved first lasing in 2017 and meanwhile three SASE FEL beamlines are in operation. An increasing number of users has great interest in a specific type of two-color pump-probe experiments in which high-field THz pulses are employed to drive nonlinear processes and dynamics in matter selectively. Here, we propose to use a 10-period superconducting THz undulator to provide intense, narrowband light pulses tunable in wide range between 3 and 100 THz. The exploitation of superconducting technology allows us to meet the challenge of generating such low photon energy radiation despite the very high electron beam energy at the European XFEL. In this presentation, we will present the latest development concerning THz undulator design and present the expected THz pulse properties for the case of the European XFEL.

TUP005 Feasibility Study of an External-Laser Seeding for the European XFEL

***T. Tanikawa**, M. Adachi, G. Geloni, S. Karabekyan, M. Lederer, S. Serkez, S. Tomin (EuXFEL) M. Adachi (KEK)*

In 2017, the European XFEL successfully achieved first lasing. Currently, up to 3 SASE FEL lines, SASE1, SASE2, and SASE3 can be operated quasi-simultaneously. Mid-term upgrades for the European XFEL are now under discussion, which will consist in the implementation of two novel XFEL lines, SASE4 and SASE5. One feasible idea for a soft X-ray FEL line consists of an external-seeded FEL, which would largely increase the longitudinal coherence properties of the radiation, compared to SASE, and will be just as powerful. In this presentation, we will report about the current status of our studies on external laser seeding feasibility using the high-electron beam energy of the European XFEL, with cascaded High-Gain Harmonic Generation (HGHG) and Echo-Enabled Harmonic Generation (EEHG).

TUP006 The FHI FEL Upgrade Design

***W. Schöllkopf**, M. De Pas, D. Dowell, S. Gewinner, H. Junkes, G. Meijer, G. von Helden (FHI) W.B. Colson (NPS) S.C. Gottschalk (STI Magnetics LLC) J. Rathke, T. Schultheiss (AES) A.M.M. Todd (AMMTodd Consulting) L.M. Young (LMY Technology)*

Since coming on-line in November 2013, the Fritz-Haber-Institut (FHI) der Max-Planck-Gesellschaft (MPG)

Free-Electron Laser (FEL) has provided intense, tunable infrared radiation to FHI user groups. It has enabled experiments in diverse fields ranging from bio-molecular spectroscopy to studies of clusters and nanoparticles, nonlinear solid-state spectroscopy, and surface science, resulting in 50 peer-reviewed publications so far. A significant upgrade of the FHI FEL is now being prepared. A second short Rayleigh range undulator FEL beamline is being added that will permit lasing from < 5 microns to > 160 microns. Additionally, a 500 MHz kicker cavity will permit simultaneous two-color operation of the FEL from both FEL beamlines over an optical range of 5 to 50 microns by deflecting alternate 1 GHz pulses into each of the two undulators. We will describe the upgraded FHI FEL physics and engineering design and present the plans for two-color FEL operations in November 2020.

TUP007 **Experience with the Superradiant THz User Facility Driven by a Quasi-CW SRF Accelerator at ELBE**

M. Bawatna, *B.W. Green (HZDR)*

Instabilities in beam and bunch parameters, such as bunch charge, beam energy or changes in the phase or amplitude of the accelerating field in the RF cavities can be the source of noise in the various secondary sources driven by the electron beam. Bunch charge fluctuations lead to intensity instabilities in the superradiant THz sources. The primary electron beam driving the light sources has a maximum energy of 40 MeV and a maximum current of 1.6 mA. Depending on the mode of operation required there are two available injectors in use at the ELBE. The first is the thermionic injector, which is used for regular operating modes and supports repetition rates up to 13 MHz and bunch charges up to 100 pC. The second is the SRF photocathode injector, which is used for experiments that may require lower emittance or higher bunch charges of up to 1 nC. It has a maximum repetition rate of 13 MHz which can be adjusted to lower rates if desired, also including different macro pulse modes of operation. In this contribution, we will present our work in the pulse-resolved intensity measurement that allows for correction of intensity instabilities.

TUP008 **Concept of High-Power CW IR-THz Source for the Radiation Source Elbe Upgrade**

P.E. Evtushenko, *T.E. Cowan, U. Lehnert, P. Michel (HZDR)*

The Radiation Source ELBE at HZDR is a user facility based on a 1 mA, 40 MeV CW SRF LINAC. HZDR is considering upgrade options for the ELBE or its replacement with a new user facility. A part of the user requirements is the capability to generate IR and THz pulse in the frequency range from 0.1 through 30 THz, with pulse energies in the range from 100 uJ through a few mJ, at the repetition rate between 100 kHz and 1 MHz. In this contribution, we outline key aspects of a concept, which would allow achieving such parameters. Such key aspects are: use of a beam with longitudinal density modulation and bunching factor of about 0.5 at the fundamental frequency; achieving the density modulation through the mechanism similar to the one used in optical klystron (OK) and HGHG FEL, generation necessary for the modulation optical beam by an FEL oscillator, using two electron injectors, where one injector provides a beam for the FEL oscillator while second high charge injector provides beam for the high energy per pulse generation for user experiments. All-in-all the concept of the new radiation source is very similar to an OK, but operating with two beams simultaneously.

TUP009 **Integration of an XFELO at the European XFEL Facility**

P. Rauer, *I. Bahns, W. Hillert, J. Roßbach (University of Hamburg, Institut für Experimentalphysik) W. Decking (DESY) H. Sinn (EuXFEL)*

An X-ray free-electron laser oscillator (XFELO) is a fourth generation X-ray source promising radiation with full three dimensional coherence, nearly constant pulse to pulse stability and more than an order of magnitude higher peak brilliance compared to SASE FELs. Proposed by Kim et al. in 2008 an XFELO follows the concept of circulating the light in an optical cavity - as known from FEL oscillators in longer wavelength regimes - but uses Bragg reflecting crystals instead of classical mirrors. With the new European X-ray Free-Electron Laser (XFEL) facility recently gone into operation, the realization of an XFELO with radiation in the Angstrom regime seems feasible. Though, the high thermal load of the radiation on the cavity crystals, the high sensibility of the Bragg-reflection on reflection angle and crystal temperature as well as the very demanding tolerances of the at least 60 m long optical resonator path pose challenges which need to be considered. In this work these problems shall be summarized and results regarding the possible integration of an XFELO at the European XFEL facility will be presented.

TUP010 **Stimulated Emission of THz Coherent Diffraction Radiation**

Y. Honda, *A. Aryshev, R. Kato, T. Miyajima, T. Obina, M. Shimada, R. Takai, T. Uchiyama, N. Yamamoto (KEK)*

We have been developing a unique terahertz radiation source of resonant coherent diffraction radiation at cERL in KEK. An optical resonant cavity consists of two concave mirrors with a beam hole at the center was installed in the return-loop of cERL, an energy-recovery linac test facility at KEK. When the low-emittance and short bunch length multi-bunch electron beam passes through the cavity, it radiates coherent diffraction radiation in the cavity. If the round-trip time of the cavity precisely matches the beam repetition, the radiation of the bunches are stacked coherently and stimulates the beam-to-radiation energy conversion process. Measuring the terahertz radiation power while scanning the cavity length, we observed a sharp resonance of THz stimulated emission associated with beam deceleration.

TUP011 **Upgrade Options for Infrared FEL to be Constructed at cERL**

Y. Honda, *R. Kato, M. Shimada (KEK) K. Kawase (QST) F. Sakamoto (Akita National College of Technology)*

We have started construction of an infrared SASE FEL system at the return loop of cERL, an energy-recovery-linac test facility at KEK. The main purpose of this project is a demonstration of industrial use of FEL, for example non-thermal processing of materials. It also has a purpose of developing necessary techniques for a future ERL-based FEL. The present design consists of two 3 m undulators and a matching space between the undulators. As future upgrade options, we have considered possibilities of various schemes, such as regenerative amplifier, quasi self-seeding, undulator tapering, etc. We will present simulation results.

TUP012 Smith-Purcell Radiation Emitted by Pico-second Electron Bunches from a 30 keV Photo-Electron Gun

***M.R. Asakawa** (Kansai University)*

In this paper, an experiment to generate Smith-Purcell radiation using pico-second electron bunches is reported. The electron bunch was produced by a DC 30 keV photo-electron electron gun driven by a 100 fs Ti:sapphire laser. The charge of the bunch varied from 1 pC to 300 pC by changing the laser power. Smith-Purcell radiation experiment was performed with the central part of the entire electron bunch. Estimation of pulsewidth of the bunch based on the envelope equation showed that the pulsewidth of the bunch at the anode electrode increased from 0.8 ps to 3.2 ps as the bunch charge increase from 0.1 pC to 11 pC. Such electron bunch was traveled along the surface of the metallic grating with a period of 2 mm. The radiation wavelength was estimated to be 4 mm at an obserbation angle of 10 degree. The radiation power was measured by a bolometer and quadraticallly increased with the bunch charge. Numerical simulation of this experiment indicated the enhancement of the harmonic components of the radiation. We are now constructing a THz-TDS system to measure the time-trace of the electric field of the radiation.

TUP013 High Extraction Efficiency Operation of Mid-Infrared Free Electron Laser in Kyoto University Enabled by Dynamic Cavity Desynchronization

***H. Zen**, H. Ohgaki (Kyoto University) R. Hajima (QST)*

The extraction efficiency is an important parameter which determines the Free Electron Laser (FEL) performance. High extraction efficiency (5.5 percent) of the mid-infrared FEL in Kyoto University (KU-FEL) has been achieved by introducing the dynamic cavity desynchronization, i.e. optimized electron bunch frequency modulation in a macro-pulse. The extraction efficiency was evaluated by measuring the change of electron beam energy distribution after the undulator with and without FEL lasing. To our best knowledge, the achieved extraction efficiency (5.5 percent) is the highest extraction efficiency being reported on oscillator FELs driven by normal conducting accelerators. Numerical simulations have also been performed and they showed good agreement with the experimental results.

TUP014 Crossed-Undulator Configuration for Variable Polarized THz Source

***H. Hama**, F. Hinode, S. Kashiwagi, N.M. Morita, T. Muto, K. Nanbu, H. Saito (Tohoku University, Research Center for Electron Photon Science)*

We have developed crossed-undulator configuration to control the polarization of coherent THz radiation at the femto-second electron beam facility, t-ACTS, that has been established at Research Center for Electron Photon Science, Tohoku University. The t-ACTS linac equips a thermionic RF gun, a 3 m accelerating structure and a 50 MW klystron modulator. Ultra-short electron bunch (~80 fs) train can be supplied via velocity bunching scheme. The crossed-undulator system is consisted with two identical transverse undulators intersected by a chicane type phase shifter. Deflecting planes of two undulators are at right angles each other, and the phase shifter makes path length difference between the electrons and the radiation. Target radiation frequency is around 2 THz employing a beam energy of 22 MeV. Since electron bunch trails behind the radiation by the slippage-effect and the nonrelativistic-effect that the electron speed is a bit slower than the speed of light, the radiation from 1st undulator has to be much delayed rather than the electrons. The paper will report the characteristics of polarized radiation and designing work of the phase shifter.

TUP015 Design of Terahertz Super-Radiation for CAEP THz FEL Facility Based on Superconducting Accelerator

***D. Wu**, M. Li, P. Li, L.G. Yan (CAEP/IAE)*

China Academy of Engineering Physics terahertz free electron laser (CAEP THz FEL, CTFEL) is the first THz FEL oscillator in China. The super-radiation of the ultra-short electron beam bunches could generate broadband Terahertz with high average power by the means of the high-voltage DC photo-cathode gun and the superconducting accelerator of CTFEL, which complement the free electron laser. In this paper, the optimization dynamic and the design of the super-radiation are introduced. The optimization is based on the differential evolution with multi-parameter and single-objective. Both designs based on coherent undulator radiation and coherent transition radiation are also discussed.

TUP016 Development of a Compact THz FEL Using a Hybrid Electro-Magnetic Planar Undulator With Horizontal Focusing Force

***S. Bae**, M.Y. Jeon, T. Yun (Chungnam National University) B.A. Gudkov, K.H. Jang, Y.U. Jeong, K. Lee, S.V. Miginsky (KAERI)*

A compact terahertz free electron laser is under development at KAERI for security and defense applications. In the system, a compact microtron is driven by a magnetron with a frequency of 2.8 GHz. The energy, peak current, and energy spread of the electron beam are 5 MeV, ~1 A, and 0.4-0.5%, respectively. A hybrid electro-magnetic planar undulator was designed and fabricated with the lasing wavelength range of 350-650 µm. The magnetic field strength in the gap of the undulator is adjustable to 0.76-1.18 T by changing the coil current of the undulator 1.4-2.4 kA. The undulator provides independent horizontal focusing force for each magnet field strength. That is necessary to keep the electron beam in a narrow waveguide. The undulator field error of 1st and 2nd integrals , which is 0.288×10^{-4} T·m and 0.136×10^{-5} T·m^2, respectively. It is minimized the diffraction angle and trajectory offset when the electron beam pass through the waveguide.

TUP017 Terahertz FEL Simulation in PAL XFEL

***J.H. Ko**, H.-S. Kang (PAL)*

Terahertz radiation is being used in various fields such as imaging, diagnosis, inspection, etc. For the terahertz research, the Pohang accelerator laboratory (PAL) is planning to make a terahertz free electron laser based on self-amplified spontaneous emission (SASE). Using free electron laser method, we can conduct the THz-pump x-ray probe experiment. For the terahertz free electron laser, we conducted the simulation on accelerators below 40 MeV, using photo-cathode RF gun, S-band accelerator and undulator below 6 meters.

TUP018 **Superradiant Emission of Electron Bunches Based on Cherenkov Excitation of Surface Waves in 1D and 2D Periodical Lattices: Theory and Experiments**

A. Malkin, *N.S. Ginzburg, A. Sergeev, I.V. Zheleznov, I.V. Zotova (IAP/RAS) M.I. Yalandin (RAS/IEP) V.Yu. Zaslavsky (UNN)*

In recent years, significant progress was achieved in generation of high-power ultrashort microwave pulses based on superradiance (SR) of electron bunches extended in the wavelength scale. In this process, coherent emission from the entire volume of the bunch occurs due to the development of microbunching and slippage of the wave with respect to electrons. An obvious method for generation of high-power sub-THz radiation is the implementation of oversized periodical slow-wave structures where evanescent surface waves can be excited. We report of the experiments on Cherenkov generation of 150 ps SR pulses with a central frequency of 0.14 THz, and an extremely high peak power up to 70 MW. In order to generate spatially coherent radiation in shorter wavelength ranges (including THz band) in strongly oversized waveguiding systems, we propose a slow wave structure with double periodic corrugation (2D SWS). Using the quasi-optical theory and PIC simulations, we demonstrate the applicability of such 2D SWS and its advantages against traditional 1D SWS. Proof of principle experiments on observation G-band Cherenkov SR in 2D SWS are currently in progress.

TUP019 **Regime of Multi-Stage Non-Resonant Trapping in Free Electron Lasers**

A.V. Savilov, *I.V. Bandurkin, Yu.S. Oparina, N.Yu. Peskov (IAP/RAS)*

We describe three works united by the idea of the non-resonant regime providing an effective trapping in a beam with a great energy spread. In this regime, the "bucket" corresponding to the resonant electron-wave interaction passes through the electron layer on the energy-phase plane and traps a fraction of electrons. (I) Operability of this regime was demonstrated in the high-efficient 0.8 MeV Ka-band FEM-amplifier. (II) In short-wavelength FELs the multi-stage trapping in several consecutive sections can be organized. In each section a small e-beam fraction is trapped due to a weak electron-wave interaction. However, repetition of this process from section to section involves in the interaction almost the whole e-beam. We describe efficiency enhancement and improving the frequency wave spectrum in multi-stage SASE FELs. (III) The multi-stage amplification of a single-frequency wave signal can provide cooling of the electron bunch. In this regime, tapering of every section is provided such that the "bucket" goes from maximal initial electron energy down to the minimal one and moves down energies of trapped electrons.

TUP020 **Terahertz Free Electron Maser Based on Excitation of a Talbot-Type Super-Mode in an Oversized Microwave System**

A.V. Savilov, *Yu.S. Oparina, N.Yu. Peskov (IAP/RAS)*

A natural problem arising in the case of realization of a THz FEM with a high-current relativistic e-beam is an inevitable use of an oversized microwave system, which characteristic transverse size significantly exceeds the wavelength of the operating wave. In this situation, it becomes difficult to provide selective excitation of a chosen transverse mode of the operating cavity. Our basic idea is to give up working on a fixed transverse mode. Instead, we propose to work on a supermode, which is a fixed set of several transverse modes of an oversized wavegude. We propose to use the Talbot effect as a way to create an oversized microwave system of an electron maser that provides a high Q-factor for this supermode. On the basis of a multi-mode set of self-consistent equations of the electron-wave interaction we demonstrate the possibility of the selective self-excitation of the supermode both in the simplest 2-D model and in the detailed modeling of a THz FEM fed by a 10 MeV / 2 kA / 200 e-beam based on excitation of a Talbot-type supermode at a frequency close to 2 THz. The calculated efficiency at the level of 5-10% corresponds to the GW level of the output power.

TUP021 **Development of Powerful Long-Pulse Terahertz Band FELs Based on Linear Induction Accelerators**

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The paper is devoted to development of high-power long-pulse THz-band FELs based on new generation of linear induction accelerators which have been elaborated recently at Budker Institute (Novosibirsk). These accelerators generate microsecond electron beams with current at kA-level and energy of 2 to 5 MeV (with a possibility to increase electrons energy up to 20 MeV). Based on this beam, we initiated a new project of multi-MW long-pulse FEL operating in the frequency range of 1 to 10 THz using a wiggler period of 3 to 6 cm. For this FEL oscillator, we suggest a hybrid planar two-mirror resonator consisting of an upstream highly selective advanced Bragg reflector and a downstream weakly reflecting conventional Bragg reflector. Simulations demonstrate that the advanced Bragg reflector based on coupling of propagating and quasi-cutoff waves ensures the mode control at the values of the gap between the corrugated plates forming such resonator up to 20 wavelengths. Simulations of the FEL driven by electron beam generated by the LIU'2 in the frame of both averaged approach and 3D PIC code demonstrate that the THz radiation power can reach the level of 10 to 20 MW.

TUP023 **Analytical and Numerical Comparison of Different Approaches to the Description of SASE in High Gain FELs**

O.A. Shevchenko, *N.A. Vinokurov (BINP SB RAS) N.A. Vinokurov (NSU)*

Correlation function theory which has been developed recently gives rigorous statistical description of the SASE FEL operation. It directly deals with the values averaged over many shots. There are two other approaches which are based either on Vlasov equation or on direct solution of particle motion equations. Both of them use random functions which relate to single shot. To check the validity of these three approaches it might be interesting to compare them with each other. In this paper we present the results of such comparison obtained for the 1-D FEL model. We show that two-particle correlation function approximation is equivalent to the quasilinear approximation of the Vlasov equation approach. These two approximations are in a good agreement with the results of direct solution of particle motion equations at linear and early saturation stages. To obtain this agreement at strong saturation high order harmonics in Vlasov equation have to be taken into account which corresponds to taking into account of three and more particle correlations in the correlation function approach.

TUP024 **Electronic Modulation of the FEL-Oscillator Radiation Power Driven by ERL**

O.A. Shevchenko, *E.V. Bykov, Ya.V. Getmanov, S.S. Serednyakov, S.V. Tararyshkin (BINP SB RAS) M.V. Fedin, A.R. Melnikov, S.L. Veber (International Tomography Center, SB RAS) Ya.V. Getmanov, S.S. Serednyakov (NSU)*

FEL oscillators usually operate in CW mode and produce periodic train of radiation pulses but some user experiments require modulation of radiation power. Conventional way to obtain this modulation is using of mechanical shutters but it cannot provide very short switching time and may lead to decreasing of the radiation beam quality. Another way could be based on the electron beam current modulation but it cannot be used in the ERL. We propose a simple way of fast control of the FEL lasing which is based on periodic phase shift of electron bunches with respect to radiation stored in optical cavity. The phase shift required to suppress lasing is relatively small and it does not change significantly repetition rate. This approach has been realized at NovoFEL facility. It allows to generate radiation macropulses of desirable length down to several microseconds (limited by quality factor of optical cavity and FEL gain) which can be synchronized with external trigger. We present detailed description of electronic power modulation scheme and discuss the results of experiments.

TUP025 **Current Status of Free Electron Laser @ TARLA**

A.A. Aksoy, *Ö. Karslı, Ç. Kaya, İ.B. Koc (Ankara University, Accelerator Technologies Institute) Ö.F. Elçim (Ankara University Institute of Accelerator Technologies)*

Turkish Accelerator and Radiation Laboratory (TARLA), which is supported by the Presidency Strategy and Budget Directorate of Turkey, aims to be the state of art research instrument based on radiation sources for users from Turkey. Two superconducting accelerators of TARLA will drive two different NbFe hybrid undulator magnets with periods of 110 mm (U110) and 35 mm (U35). Free Electron Laser (FEL) beamlines will provide Continuous Wave (CW) tunable radiation of high brightness in between 5-350 µm as well as a Bremstrahlung radiation station. In this study, preliminary calculation results of GENESIS and Optical Propagation Code (OPC), light beam interaction within the undulator and the propagation of the light outside the undulator and current status of the facility are presented.

TUP026 **An Unaveraged Simulation of Regenerative Amplifier Free Electron Laser**

P. Pongchalee, *B.W.J. M^c^Neil (USTRAT/SUPA) B.W.J. M^c^Neil (Cockcroft Institute)*

A regenerative amplifier free electron laser (RAFEL) simulation and design require the model in both of the electron-light interaction in the undulator and optical propagation outside the undulator as the oscillation cavity. An unaveraged 3D simulation of the free electron laser (FEL), named Puffin has been used to model the FEL interaction within the undulator, providing the optical field with the fast-oscillating term for broadband and high-resolution FEL simulation, whilst the Optical Propagation Code (OPC) is used to model the optical beam propagation outside the undulator and the optical field diagnostic at the location of the cavity mirrors. This paper presents the optical field conversion method between Puffin and OPC codes. Then it will demonstrate the regenerative amplifier VUV-FEL model.

TUP027 **Modelling Crystal Misaligments for the X-ray FEL Oscillator**

R.R. Lindberg *(ANL)*

The X-ray FEL oscillator has the potential to be a revolutionary new light source providing unprecedented stability in a narrow bandwidth. However, a detailed understanding of cavity tolerance and stability has only begun, and there are presently no suitable simulation tools. To address this issue, we have developed a fast FEL oscillator code that discretizes the field using a Gauss-Hermite mode expansion of the oscillator cavity. Errors in crystal alignment result in a mixing of the modes that is easily modeled with a loss and coupling matrix. We show first results from our code, including the effects of static and time-varying crystal misalignments.

TUP028 **Power Variations of an X-ray FEL Oscillator in Saturation**

R.R. Lindberg *(ANL)*

Basic FEL theory predicts that the fractional power fluctuations of an ideal oscillator in steady state should be given by the ratio of the spontaneous power in the oscillator bandwidth to that stored in the cavity at saturation. For the X-ray FEL oscillator with its narrow bandwidth Bragg crystal mirrors, this ratio is typically a few parts per million, but some simulations have shown evidence of power oscillations on the percent level. We show that these are purely numerical, and can be eliminated by changing the particle loading. We then briefly discuss to what extent fluctuations in electron beam and cavity parameters may degrade the power stability.

TUP029 **Efficient Output Coupling From X-Ray Free-Electron Laser Cavities**

Yu. Shvyd'ko *(ANL)*

Permeable mirrors are typically used for coupling photons out of laser cavities. A similar approach was proposed for output coupling photons from the cavities of X-ray free-electron laser oscillators (XFELO). One of Bragg-reflecting crystal mirrors is thin, just a few extinction length, and is used as a permeable mirror. However, this method is very often limited to extraction of only a few tenths of the intracavity power. Other cavity-based XFEL schemes, such as the high-gain regenerative amplifier X-ray free-electron lasers (XRAFEL), require much higher outcopling efficiency. Here alternative schemes are proposed and analyzed for coupling X-ray photons out of XFEL cavities using intracavity Bragg-reflecting X-ray-transparent diamond crystal beam splitters. They are efficient and flexible in terms of the amount of the power coupled out of the cavity, which can vary promptly from zero to close to 100%. The schemes can be readily extended to multi-beam outcoupling.

TUP030 An X-ray Regenerative Amplifier Free-Electron Laser Using Diamond Pinhole Mirrors

***H. Freund** (University of New Mexico) , Yu. Shvyd'ko (ANL) P.J.M. van der Slot (Mesa+)*

Free-electron lasers (FELs) have been built ranging in wavelength from long-wavelength oscillators through hard x-ray FELs that are either seeded or start from noise (SASE). X-ray operation has relied on single-pass SASE due either to the lack of seed lasers or difficulties in the design of x-ray mirrors. However, recent developments in the production of diamond crystal Bragg reflectors point the way toward x-ray regenerative amplifiers (RAFELs) which are, essentially, low-Q free-electron laser oscillators that outcouple a large fraction of the optical power on each pass. A RAFEL using a six-mirror resonator providing out-coupling of 90% or more through a pinhole in the first downstream diamond mirror is proposed and analyzed using the MINERVA simulation code for the undulator interaction and the Optics Propagation Code (OPC) for the resonator. OPC has been modified to treat Bragg reflection from diamond crystal mirrors. Simulations have been run to optimize and characterize the properties of the RAFEL, using the LCLS-II HXR undulator under construction at SLAC, and indicate that substantial powers are possible at the fundamental (3.05 keV) and third harmonic (9.15 keV).

TUP031 Precision Gamma-Ray Beam Polarization Control Enabled Using Crossed Undulator Oscillator FEL

***J. Yan**, H. Hao, P. Liu, S.F. Mikhailov, V. Popov, Y.K. Wu (FEL/Duke University) S. Huang (PKU) J.Y. Li (IHEP) V. Litvinenko (Stony Brook University) N.A. Vinokurov (BINP SB RAS)*

A polarized gamma-ray beam with controllable polarization is a powerful probe for experimental nuclear physics research, enabling the investigation of nuclei and hadrons by directly accessing polarization dependent observables. In this work, we report new ways to precisely control the polarization of a Free-Electron Laser (FEL) driven Compton scattering gamma-ray source. Using an FEL oscillator and two helical undulators with opposite helicities, we have successfully produced a nearly 100% linearly polarized laser beam without using conventional polarizing optics. By tuning the phase between two helical undulators, the direction of polarization can be arbitrarily and precisely adjusted. With this FEL as the photon drive, a Compton gamma-ray beam has been generated with its polarization in any of the base states, including left- and right-circular polarization and rotatable linear polarization. The linearly polarized gamma-ray beam with arbitrary polarization direction has been imaged and characterized, and shows a high degree of linear polarization ($P_L$in = 0.97).

TUP032 Regenerative Amplification for a Hard X-ray Free-Electron Laser

***G. Marcus**, Y. Ding, Y. Feng, Z. Huang, J. Krzywiński, J.P. MacArthur, R.A. Margraf, T.O. Raubenheimer, D. Zhu (SLAC)*

An X-ray regenerative amplifier FEL (RAFEL) utilizes an X-ray crystal cavity to provide optical feedback to the entrance of a high-gain undulator. A RAFEL system leverages gain-guiding in the undulator to reduce the cavity alignment tolerances and targets the production of longitudinally coherent and high peak power and brightness X-ray pulses that could significantly enhance the performance of a standard single-pass SASE amplifier. The successful implementation of an X-ray cavity in the RAFEL scheme requires the demonstration of X-ray optical components that can either satisfy large output coupling constraints or passively output a large fraction of the amplified coherent radiation. Here, we present new schemes to either actively Q-switch a diamond Bragg crystal through lattice constant manipulation or passively output couple a large fraction of the stored cavity radiation through controlled FEL microbunch rotation. A beamline design study, cavity stability analysis, and optimization will be presented illustrating the performance of potential RAFEL configurations at LCLS-II/-HE using high-fidelity simulations. Initial cold-cavity tests planned for 2020 will also be discussed.

TUP033 Q-Switching of X-Ray Optical Cavities With a Boron Doped Buried Layer Under the Surface of a Diamond Crystal

***J. Krzywiński**, Y. Feng, G. Marcus, D. Zhu (SLAC)*

Improvement of the longitudinal coherence of X-ray Free Electron Lasers has been the subject of many recent investigations. The XFEL oscillator (XFELO) and Regenerative Amplifier Free-Electron Laser (RAFEL) schemes offer a pathway to fully coherent, high brightness X-ray radiation. The XFELO and RAFEL consist of a high repetition rate electron beam, an undulator and an X-ray crystal cavity to provide optical feedback. The X-ray cavity will be based on diamond crystals in order to manage a high thermal load. We are investigating a 'Q switching' mechanism that involves the use of a 'Bragg switch' to dump the X-ray pulse energy built-up inside an X-ray cavity. In particular, one can use an optical laser to manipulate the diamond crystal lattice constant to control the crystal reflectivity and transmission. It has been shown that a 9 MeV focused boron beam can create a buried layer, approximately 5 microns below surface, with a boron concentration up to 10^{21} atoms/cm^3. Here, we present simulations showing that absorbing laser pulses by a buried layer under the crystal surface would allow creating a transient temperature profile which would be well suited for the 'Q switching' scheme.

TUP034 Statistical Properties of a Self-Seeded FEL With Pedestal Growth

***E. Hemsing**, W.M. Fawley, G. Marcus, Z. Zhang (SLAC)*

In self-seeded FELs, SASE pulses from the first portion of the FEL are monochromatized and then amplified in the downstream portion to produce output pulses with a narrow bandwidth and higher degrees of temporal coherence. Owing to its SASE origin, it is well known that the seed radiation after the monochromator exhibits statistical fluctuations which depend, in part, on the monochromator linewidth. In addition, it was recently shown that the narrow bandwidth seed amplification can be accompanied by a wider bandwidth pedestal-like signal due to SASE and MBI, which are also stochastic in nature. We examine how, during amplification of the seed, spectral pedestal growth can also impact the statistical properties of the FEL output.

TUP035 **Sensitivity of LCLS Self-Seeded Pedestal Emission to Laser Heater Strength**

***G. Marcus**, D.K. Bohler, Y. Ding, W.M. Fawley, Y. Feng, E. Hemsing, Z. Huang, J. Krzywiński, A.A. Lutman, D.F. Ratner (SLAC)*

Measurements of the soft X-ray, self-seeding spectrum at the LCLS free-electron laser generally display a pedestal-like distribution around the central seeded wavelength that degrades the spectral purity. We have investigated the detailed experimental characteristics of this pedestal and found that it is comprised of two separate components: (1) normal SASE whose total strength is nominally insensitive to energy detuning and laser heater (LH) strength; (2) sideband-like emission whose strength positively correlates with that of the amplified seed and negatively with energy detuning and LH strength. We believe this latter, non-SASE component arises from comparatively long wavelength amplitude and phase modulations of the main seeded radiation line. Its shot-to-shot variability and LH sensitivity suggests an origin connected to growth of the longitudinal microbunching instability on the electron beam. Here, we present experimental results taken over a number of shifts that illustrate the above mentioned characteristics.

TUP036 **A Waveguide-Based High Efficiency Super-Radiant FEL Operating in the THz Regime**

***P. Musumeci**, A.C. Fisher (UCLA) A. Gover (University of Tel-Aviv, Faculty of Engineering) E.A. Nanni, E.J. Snively (SLAC) S.B. van der Geer (Pulsar Physics)*

In this paper we describe self-consistent 3D simulations for a waveguide FEL operating in the zero-slippage regime to generate high power THz radiation. In this regime the phase and group velocity of the radiation are matched to the relativistic beam traveling in the undulator and long interaction lengths can be achieved. Our approach is based on following the energy exchange of the particles in the beam with the electromagnetic field modes of the waveguide. We study a particular test case where by tapering the undulator a large fraction of the input beam energy can be extracted and converted to THz radiation. This scheme can be useful in the quest for high average and peak power THz sources.

TUP037 **Optimization of the Transverse Gradient Undulator (TGU) for Application in a Storage Ring Based XFELO**

***Y.S. Li** (University of Chicago) K. Kim, R.R. Lindberg (ANL)*

The stringent energy spread requirement of the XFELO poses a challenge for its application in storage rings. One way to overcome this is by using a transverse gradient undulator (TGU). In the 1D approximation, the TGU gain formula was discussed previously. In this paper, we begin by deriving an analytical gain formula valid in 3D from the gain convolution formula. Following that, we apply numerical optimization to investigate the optimal beam and field parameters for maximal TGU gain. The parameters of interest include the natural beam emittance, emittance ratio, beam energy spread, dimensionless TGU strength, as well as usual beam and field parameters (beta functions, Rayleigh ranges, and detuning). We found that a small emittance ratio (i.e. "flat beam" configuration) has a strong positive impact on TGU gain, as well as other patterns in the optimal parameters. We conclude with a discussion of the practical implications for a storage ring driven XFELO.

TUP038 **Axial Symmetry in Spontaneous Undulator Radiation and FEL Gain**

***Y.S. Li** (University of Chicago) K. Kim, R.R. Lindberg (ANL)*

A well known discrepancy exists between FEL simulation codes GENESIS and GINGER with respect to the radiation field intensity during the initial period when it is dominated by spontaneous undulator radiation (SUR). This can be qualitatively explained by the fact that the 3D field representation of GENESIS preserves many more modes than does the axisymmetric field solved for by GINGER. In this paper, we seek to develop an analytical model that quantifies this difference. We begin by expanding the SUR field as a multipole series, whose lowest order mode is axisymmetric. This allows us to calculate the difference in predicted intensity. Next, we examine the FEL gain experienced by these modes. Finally, we discuss the implications of this study with respect to a proposed XFELO test experiment.

TUP039 **Radiation Reaction, Space-Charge and Thermal Effects in Free-Electron Lasers**

***E.A. Peter**, A. Endler, F.B. Rizzato (IF-UFRGS) S. Marini (LULI)*

In the present work, a theoretical high gain single pass one-dimensional free-electron laser is modelled, including space-charge and thermal effects. The role of the radiation reaction over the system dynamics is explored in a second moment: its effect is obtained via Landau-Lifschitz equations. Some simplifications are done, as the fields of the laser and of the wiggler, which are assumed to be independent of the transversal coordinates. The results are obtained through simulations, using a code developed by the group.

TUP040 **Interferometric Effects on Laser Plasma Accelerator Based Forthcoming FELs**

***M. Labat**, M.-E. Couprie, A. Loulergue (SOLEIL) S. Bielawski, E. Roussel (PhLAM/CERCLA) S. Bielawski, E. Roussel (PhLAM/CERLA)*

The demonstration of a Free Electron Laser amplification on a Laser Plasma Accelerator is presently targeted by several working groups worldwide. In this framework, the COXINEL experiment turned a corner achieving a complete control of the electron beam properties in the undulator thanks to original transport methods. Following, we reveal that the forthcoming LPA based FELs will exhibit specific as well as unobserved spectral features. In the seeded mode, the FEL radiation will be indeed red shifted with respect to the seed wavelength while interference fringes will be highly visible in both near and far fields. Relying on simple theoretical models, we explain the physical phenomena originating those behaviors. Stepping further, we show how our interferometric model enables a full temporal reconstruction of the FEL pulse temporal amplitude and phase distributions.

TUP041 **X-cos SCILAB Model for Simulation of Intensity and Gain of Planar Undulator Radiation**

***H. Jeevakhan** (NITTTR) G. Mishra (Devi Ahilya University)*

SCILAB X-cos based model has been designed to simulate the Intensity and Gain of planar undulator radiation. Numerical approach has been used to determine the trajectories of an electron along x and z direction,

traversing through a planar undulator. The present paper describes the technical details of the different blocks, parameters and possibility of combined model used for trajectory and intensity simulation Results are compared with the previous conventional syntax based codes.

TUP042 **Analysis of Undulator Radiations With Asymmetric Beam and Non-Periodic Magnetic Field**

H. Jeevakhan *(NITTTR) G. Mishra (Devi Ahilya University)*

Harmonic Undulator radiations at third harmonics with non periodic constant magnetic field has been analysed. Symmetric and asymmetric electron beam with homogeneous spread has been used to present viable solution for the resonance shift inherited in undulator with constant magnetic field. The radiation recovers shifts in resonance and regain its intensity with asymmetric electron beam and harmonic field

TUP043 **Investigation Quantum Regime of a Plasma-Wave-Pumped Ion-Channel Free-Electron Laser**

M. Alimohamadi *(Farhangian University) A. Zarei (Shahrood University of Technology)*

The operation of quantum free-electron lasers (QFELs) with a plasma-whistler-wave-pumped in the presence of ion-channel guiding is considered. The quantum Hamiltonian of a single particle has been derived in the Bambini-Renieri (BR) frame. Time-dependent wave function and three constants of motion are obtained. Also, the quantum dispersion relation of the plasma whistler wiggler has been obtained analytically.

TUP044 **Coherent Spontaneous Superradiance and Stimulated-Superradiant Emission of Bunched Electron Beams**

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We outline the fundamental processes of coherent radiation emission from a bunched charged particles beam. In contrast to spontaneous emission of radiation from a random electron beam that is proportional to the number of particles N, a pre-bunched electron beam emits spontaneously coherent radiation proportional to N^2 through the process of (spontaneous) superradiance (SP-SR) (in the sense of Dicke's). The SP-SR emission of a bunched electron beam can be even further enhanced by a process of stimulated-superradiance (ST-SR) in the presence of a seed injected radiation field. These coherent radiation emission processes are presented in term of a radiation mode expansion model, applied to general free electron radiation schemes: Optical-Klystron, HGHG, EEHG, and coherent THz sources based on synchrotron radiation, undulator radiation or Smith-Purcell radiation. The general model of coherent spontaneous emission is also extended to the nonlinear regime - Tapering Enhanced Stimulated Superradiance (TESSA), and related to the tapered wiggler section of seed-injected FELs. In X-Ray FELs these processes are convoluted with other effects, but they are guidelines for strategies of wiggler tapering efficiency enhancement.

TUP045 **Gain Length Fit Formula for Transverse Gradient Undulator Based FEL**

W. Liu*, Y. Jiao, S. Wang (IHEP)*

Transverse Gradient Undulator (TGU) is a novel undulator, which is an undulator with canted magnetic poles so that its vertical field has a linear dependence upon the horizontal position. TGU can be used to achieve high-gain FEL with an electron beam of which the energy spread is larger than the gain bandwidth of the FEL. The TGU based high-gain FEL theory showed that by using the variational analysis, the gain length can be obtained by solving some nonlinear equations numerically. Inspired by Xie, we present a fit formula for calculating the gain length of the fundamental mode of a TGU based FEL which provides a shortcut for calculating the gain length.

TUP046 **Applications of Asymptotic Method to Accelerator Physics**

X.J. Deng *(TUB)*

In this paper, we review the applications of asymptotic method to accelerator physics, especially in FEL research. Some new viewpoints and investigations using asymptotic method are also presented.

TUP047 **An Analysis of Optimal Initial Detuning for Maximum Energy-Extraction Efficiency**

Q.K. Jia *(USTC/NSRL)*

The phase space evolutions of trapped electrons in the phase bucket are analyzed for low gain free-electron laser (FEL) based on the calculation of the synchrotron oscillation periods, which are different for the electrons with the different initial phase and initial detuning. The optimal initial detuning for the maximum energy-extraction efficiency and the corresponding saturation length are given. The analysis demonstrated that for the low gain case the gain of the strong optical field is about a quarter of that of the weak optical field (small signal gain), and the saturation power larger than that of high gain FEL can be achieved in the resonator of oscillator FEL.

TUP048 **Collapsing Cylindrical Long Shells Filled the Periodical Magnetic Field**

V.V. Gorev *(NRC)*

The collapse of the cylindrical shell (liner) at a certain stage of compression is limited by the development of magneto hydrodynamics instabilities such as Rayleigh-Taylor. This leads to an alternating field formation within the internal volume of the liner for a short period of time, similar to the magnetic field of a usual stationary system. The magnitude of the magnetic field and space period can be adjusted over a wide range, providing a short pulse of radiation with a moderate electron energy.

TUP049 **Simulating Shot-Noise in 'Real' Electron Bunches**

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An algorithm and numerical code for the up-sampling of a system of particles, from a smaller to a larger number, is described. The method introduces a Poissonian 'shot-noise' to the up-sampled distribution, typical of the noise statistics arising in a bunch of particles generated by a particle accelerator. The algorithm is applied on a phase-space distribution of relatively few simulation particles representing an electron beam generated by particle accelerator modelling software, for subsequent injection into an Free Electron Laser (FEL) amplifier which is used here to describe the model. A much larger number of particles is usually required to model the FEL lasing process than is required in the simulation models of the electron beam accelerators that drive it. A numerical code developed from the algorithm was then used to generate electron bunches for injection into to an unaveraged 3D FEL simulation code, Puffin. Results show good qualitative and quantitative agreement with analytical theory. The program and usage manual is available to download from GitHub.

TUP050 **Comparison Between, and Validation Against an Experiment of, a Slowly-varying Envelope Approximation Code and a Particle-in-Cell Simulation Code for Free-Electron Lasers**

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Free-electron laser simulation codes employ either the Slowly-Varying Envelope Approximation (SVEA) or a Particle-in-Cell (PiC) formulation. Maxwell's equations are averaged over the fast time scale in the SVEA so that there is no need to resolve the wave period. In contrast, the fast oscillation is retained in PiC codes. As a result, the SVEA codes are much less computationally intensive and are used more frequently than PiC codes. While the orbit dynamics in PiC codes and some SVEA Codes (MEDUSA and MINERVA) use the full unaveraged Lorentz force equations, some SVEA codes use the Kroll-Morton-Rosenbluth (KMR) approximation (GENESIS, GINGER, FAST, and TDA3D). Steady-state simulation comparisons have appeared in the literature between different codes using the averaged and unaveraged particle dynamics. Recently, a comparison between three KMR SVEA codes (GENESIS, GINGER, and FAST) and the PUFFIN PiC code in the time-dependent regime has been reported. In this paper, we present a comparison between the unaveraged PiC code PUFFIN, the unaveraged SVEA code MINERVA for the time-dependent simulation of SASE free-electron lasers with the experimental measurements from SPARC SASE FEL at ENEA Frascati.

TUP051 **Plasma Accelerator Driven Coherent Spontaneous Emission**

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Plasma accelerators are a potentially important source of high energy, low emittance electron beams with high peak currents generated within a relatively short distance. As such, they may have an important application in the driving of coherent light sources such as the Free Electron Laser (FEL) which operate into the X-ray region. While novel plasma photocathodes may offer orders of magnitude improvement to the normalized emittance and brightness of electron beams compared to Radio Frequency-driven accelerators, a substantial challenge is the energy spread and chirp of beams, which can make FEL operation impossible. In this paper it is shown that such an energy-chirped, ultrahigh brightness electron beam, with dynamically evolving current profile due to ballistic bunching at moderate energies, can generate significant coherent radiation output via the process of Coherent Spontaneous Emission (CSE). While this CSE is seen to cause some FEL-induced electron bunching at the radiation wavelength, the dynamic evolution of the energy chirped pulse dampens out any high-gain FEL interaction.

TUP052 **Collective Power Radiated by Individual Electrons in a Pulse**

L. Elias *(Private Address)*

Collective electromagnetic electron radiation arises when more than one free electron is present, the amount of electromagnetic energy radiated by each electron can be larger than when it is radiating alone. In some cases, the enhanced radiation can be greater than stimulated radiation. It occurs in all free electron devices, including the FEL. Although collective radiation (CR) has been observed, the contribution of each electron in a pulse has not been properly addressed with present theories. In fact, in existing numerical simulations energy is not conserved. The formula advanced by Kimel and Elias permits evaluation of the energy radiated by each electron when other electrons are present. With the proposed correction conservation energy is re-stablished. Specific cases where CR is dominant are discussed.

TUP053 **An Investigation of Non-Standard Photon Statistics in a Free-Electron Laser I: Experiment**

J.-W. Park *(University of Hawaii) K.-J. Kim, R.R. Lindberg (ANL)*

It was reported that the photon statistics of the 7th harmonic radiation of the MARK III FEL was sub-Poissonian. Whether FEL light exhibits such non-standard behavior is an important issue; if it does, our understanding of the FEL needs to be radically modified. In this paper, we re-examine the analyses of experimental data in *T. Chen and J.M. Madey, J. Phys. Rev. Lett. 86, 5906 (2001).* concluding that Fano factor F (the ratio of photon number variance to the average photon number) is less than unity. We find that the observed value of F could be explained within the standard FEL theory if one combines the detector dead-time effect with photon clustering arising from the FEL gain. We propose an improved experiment for a more definitive measurement of the FEL statistics.

TUP054 **An Investigation of Non-Standard Photon Statistics in a Free-Electron Laser II: Theory**

J.-W. Park *(University of Hawaii) K.-J. Kim, R.R. Lindberg (ANL)*

In this paper, we explore possible theoretical basis for the non-standard photon statistics as claimed in an experiment with the Mark III FEL. We investigate the standard quantum theoretical prediction for the photon statistics of the harmonic radiation. First, we have surveyed the standard theories on the photon statistics of the FEL radiation in fundamental frequency. We find that the sub-Poissonian light cannot be generated from electron states having natural interpretations, in the linear regime of the FEL oscillator. Next, we consider a 1-D

quantum oscillator model of the harmonic radiation up to 7th harmonic in the linear regime. We start from a classical expression of harmonic radiation driven by the fundamental mode and develop a quantum description including the cavity loss in terms of the beam splitter model. If the electrons are in the minimum noise state corresponding to a localized wave function, the photon statistics are found to be super-Poissonian contrary to the observation in *T. Chen and J.M. Madey, J. Phys. Rev. Lett. 86, 5906 (2001).*

TUP055 **Two-Color Operation of FLASH2 Undulator**

E. Schneidmiller*, M. Braune, B. Faatz, U. Jastrow, M. Kuhlmann, A.A. Sorokin, K.I. Tiedtke, M.V. Yurkov (DESY)*

FLASH is the first soft X-ray FEL user facility, routinely providing brilliant photon beams for users since 2005. The second undulator branch of this facility, FLASH2, is gap-tunable which allows to test and use advanced lasing concepts. In particular, we tested recently a two-color mode of operation based on the alternation of tunes of the undulator segments (every other segment is tuned to the second wavelength). This scheme is advantageous in comparison with a subsequent generation of two colors in two different parts of the undulator. First, source positions of two FEL beams are close to each other which makes it easier to handle them. Second, the amplification is more efficient in this configuration since the segments with respectively "wrong" wavelength act as bunchers. We developed methods for online intensity measurements of the two colors simultaneously that require a combination of two detectors. We present some examples of such measurements in the XUV and soft X-ray regimes.

TUP056 **Feasibility Studies of the 100 keV Undulator Line of the European XFEL**

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The European XFEL is a multi-user X-ray FEL facility based on superconducting linear accelerator. Presently, three undulators (SASE1, SASE2, SASE3) deliver high-brightness soft- and hard- X-ray beams for users. There are two empty undulator tunnels that were originally designed to operate with spontaneous radiators. We consider instead a possible installation of two FEL undulators. One of them (SASE4) is proposed for the operation in ultrahard X-ray regime, up to the photon energy of 100 keV. In this contribution we present the results of the first feasibility studies of this option.

TUP057 **Analysis of Parameter Space of Soft X-Ray Free Electron Laser at the European XFEL Driven by High and Low Energy Electron Beam**

M.V. Yurkov*, E. Schneidmiller (DESY)*

Three undulator beamlines: SASE1 and SASE2 (hard X-ray), and SASE3 (soft X-ray) are in operation at the European XFEL serving six user instruments. Next stages of the facility development are installation of two undulator beamlines in empty tunnels SASE4 and SASE5 as medium term upgrade, and extension of the facility with the second fan of undulators as long term upgrade. Construction of soft X-ray beamlines is considered in both upgrade scenario. In the case of SASE4/SASE5 electron beam with energies 8.5 GeV - 17.5 GeV will be used in order to provide simultaneous operation of new undulator beamlines with existing SASE1-SASE3. One of the scenarios for a second fan of undulators involves using of low energy (2.5 GeV) electron beam. In this paper we analyze parameter space of soft X-ray SASE FELs driven by high energy and low energy electron beam, compare output characteristics, and discuss potential advantages and disadvantages.

TUP058 **First Characterization of the Photon Beam at the European XFEL**

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North branch of the European XFEL, SASE1, produced first light on May 3rd, 2017, and XFEL operation has been gradually improved then. First characterization of the photon beam has been performed in July / August 2017, just before an official starting date of user experiments (September 1st, 2017). Energy of the electron beam was 14 GeV, bunch charge was 500 pC, photon energy was 9.3 keV. With photon diagnostics available at that time (X-ray gas monitor (XGM) and FEL imager) we measured the gain curve and traced evolution of the FEL radiation mode along the undulator. An important conclusion is that experimental results demonstrate reasonable agreement with baseline parameters. Developed techniques of the photon beam characterization also provided solid base for identification of the problems and means for improving SASE FEL tuning and operation.

TUP059 **Influence of Energy Chirp in the Electron Beam and Undulator Tapering on Spatial Properties of the Radiation From Seeded and SASE FEL**

E. Schneidmiller*, M.V. Yurkov (DESY)*

Energy chirp and undulator tapering change resonance condition along the electron beam and undulator which results in modification of the radiation amplification process. Well known examples are post-saturation undulator tapering for radiation power increase, reverse undulator tapering for effective operation of afterburners, and application of linear undulator tapering for compensation of energy chirp effect. These are essentially one dimensional effects. In addition, energy chirp and undulator tapering also change spatial properties of the radiation which can be important for the users of X-ray FEL facilities. In this report we present detailed analysis of the spatial properties of the radiation from an FEL amplifier with tapered undulator and chirped electron beam. Two configurations, seeded FEL amplifier, and SASE FEL are under consideration. Dependence of the spatial distributions on the electron beam properties is studied, and their evolution along the undulator is traced. It is shown that spatial properties of the radiation may be significantly distorted by the effects of energy chirp in the electron beam and undulator tapering.

TUP060 **An Advanced Compression Option for the European XFEL**

***I. Zagorodnov**, M. Dohlus, E. Schneidmiller, M.V. Yurkov (DESY)*

An advanced compression scheme which allows to obtain a high peak current while preserving the low slice emittance is considered. The beam is compressed weakly in the bunch compressors and the current is increased by eSASE setup at the entrance of the undulator line. It is shown by numerical studies that such approach allows to reduce harmful collective effects in the bunch compressors and in the transport line. Simulations of FEL physics confirm the possibility to obtain a high level of SASE radiation at the ultra-hard photon energy level of 100 keV.

TUP061 **Super-X: Simulations for Extremely Hard X-Ray Generation With Short Period Superconducting Undulators for the European XFEL**

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The European XFEL is a high-repetition multi-user facility with nominal photon energy range covering almost 3 orders of magnitude: 250 eV - 25 keV. In this work we explore the possibility to extend the photon energy range of the facility up to 100 keV via combination of superconducting undulator technology, period doubling and harmonic lasing, thus allowing for excellent tunability. To this purpose, we propose a dedicated FEL line, discuss its overall concept and provide analytical and numerical estimations of its expected performance.

TUP062 **Two Colors at the SASE3 Line of the European XFEL: Project Scope and First Measurements**

***S. Serkez**, G. Geloni, N. Gerasimova, J. Grünert, S. Karabekyan, A. Koch, J. Laksman, Th. Maltezopoulos, T. Mazza, M. Meyer, S. Tomin (EuXFEL) W. Decking, L. Fröhlich, V. Kocharyan, Y.A. Kot, E. Saldin, E. Schneidmiller, M. Scholz, M.V. Yurkov, I. Zagorodnov (DESY) M. Huttula (University of Oulu) E. Kukk (University of Turku)*

The European XFEL is a high-repetition rate facility that generates high-power SASE radiation pulses in three beamlines. An upgrade project to equip the SASE3 beamline with a chicane has been recently approved to generate two SASE pulses with different photon energies and temporal separation. In this work we report the status of the project, its expected performance, and recent experimental results. Additionally, we discuss methods to diagnose the properties of the generated radiation.

TUP063 **Design of FEL-3 Undulator Line for SHINE**

***N. Huang** (SINAP) H.X. Deng (SARI-CAS)*

In this work, we present the design of FEL3 for the SHINE, the first Hard X-ray light source in China. FEL-3 undulator line covers the photon energy from 10^{-25} keV.

TUP064 **FEL Optimization Using Phaser Shifters**

***M.H. Cho** (PAL)*

Phase matching between FEL and electron beam should be precisely controlled for FEL amplification. Since undulators are segmented, a phase shifter (as a small chicane) located at each undulator entrance performs phase matching. The phase condition of the electron beam can be controlled in the in-phase or out-phase, those maximizes or minimizes FEL intensity. In this presentation, we show effects of FEL gain curve by setting the out-phase and in-phase of electron beam. For the linear amplification regime, the out-phase condition shifts the gain curve, which is obtained analytically. The saturation regime shows the out-phase condition does not amplify FEL, which is analyzed with simulations. To show no FEL amplification, KMR model is used. Our findings agrees with the experimental results performed at PAL-XFEL.

TUP065 **Optimization of a Coherent Undulator Beamline for New Advanced Synchrotron Light Source in Korea**

***I.G. Jeong**, P. Buaphad, Y.J. Joo, H.R. Lee (University of Science and Technology of Korea (UST)) P. Buaphad, Y.J. Joo, Y. Kim, H.R. Lee (KAERI) M.Y. Han, **I.G. Jeong**, J.Y. Lee, S.H. Lee (Korea Atomic Energy Research Institute (KAERI))*

Recently, the demand of a new advanced synchrotron light source in Korea is rapidly growing. Six local governments in Korea would like to host the new synchrotron light source project in their own province. The new advanced synchrotron light source will be the diffraction limited storage ring (DLSR), which is based on the MBA lattice. For the new synchrotron light source, we would like to build a special 60-m long coherent undulator beamline, which can deliver high-intensity coherent radiation at the hard X-ray region. To design the coherent undulator beamline, we have performed numerous beam dynamics simulations with GENESIS and SIMPLEX codes. In this paper, we report design concepts and those simulation results for the coherent undulator beamline.

TUP066 **Start-to-End Simulations for the Soft X-Ray FEL at the MAX IV Laboratory**

***W. Qin**, J. Andersson, F. Curbis, L. Isaksson, M. Kotur, E. Mansten, M.A. Pop, S. Thorin, S. Werin (MAX IV Laboratory, Lund University) F. Curbis, S. Werin (SLF)*

A Soft X-ray FEL (the SXL) using the existing 3 GeV linac at the MAX IV Laboratory is currently in the design phase. In this contribution, start-to-end simulations, including the photo-injector simulation using ASTRA, the linac simulation using ELEGANT and the FEL simulation using GENESIS, are presented for 100 pC and 10 pC operation mode. The features of the electron beam from the MAX IV linac and their impact on the FEL performance are discussed.

TUP067 **Advanced Concepts in the Design for the Soft X-Ray FEL at MAX IV**

***W. Qin**, F. Curbis, M.A. Pop, S. Werin (MAX IV Laboratory, Lund University) F. Curbis, S. Werin (SLF)*

A Soft X-ray FEL (the SXL) is currently being designed at the MAX IV Laboratory. In the work to adapt the FEL to the scientific cases several advanced options are being studied for coherence enhancement, generation of short pulses and two-color pulses. We will discuss the current status and the schemes studied, especially regarding the FEL performance with the features of the MAX IV linac, including a positive energy chirp.

TUP068 **Simple Method to Generate Two-Color FEL Pulses Using a Sextupole Magnet**

__P. Dijkstal__, A. Malyzhenkov, E. Prat, S. Reiche (PSI)

We present a new and simple method to produce two-color free-electron laser (FEL) pulses. In our scheme, a sextupole magnet in a dispersive location is used to impose a horizontal beam tilt. The head and tail of the bunch are aligned to the axis of the undulator beamline and will lase, while the core of the bunch undergoes orbit oscillations and thus is unable to amplify the FEL radiation. With an energy-chirped beam, the two pulses are emitted at different wavelengths. We report on simulations and first experimental studies of the generation of two-color FEL pulses using this scheme.

TUP069 **A Simple and Compact Scheme to Enhance the Brightness of SASE-FELs**

__E. Prat__, S. Reiche (PSI)

We present a simple scheme to enhance the coherence of SASE-FELs in a more compact undulator beamline. The method only requires small chicanes that can be easily installed between the undulator modules of the FEL facility. Simulations for the soft X-ray beamline of SwissFEL show that, with respect to the standard SASE case, the spectral bandwidth can be improved by up to a factor of ten and the saturation length can be reduced by 20-25%. This work has been published in *E. Prat and S.Reiche*, doi:10.1107/S1600577519005435.

TUP070 **Compact Coherence Enhancement by Subharmonic Self-Seeding in X-Ray FELs**

__E. Prat__, S. Reiche (PSI)

Self-seeding has been proven to increase the longitudinal coherence of X-ray FELs but its efficiency could be significantly improved, especially for soft X-rays. In this contribution we present a method to enhance the performance of self-seeding by combining it with the harmonic generation mechanism. In particular, by starting the process with a subharmonic of the wavelength of interest, the coherence of the produced radiation is improved, the undulator beamline becomes more compact, and the monochromator realization is simplified. Numerical simulations for SwissFEL are presented showing that the method can be employed, within a given space, to increase the spectral brightness by one order of magnitude or more with respect to standard self-seeding. This work has been published in *E. Prat and S.Reiche*, doi:10.1107/S1600577518000395.

TUP071 **Recent Results of the Large Bandwidth Operation at SwissFEL**

__S. Reiche__, E. Ferrari, E. Prat, T. Schietinger (PSI) Á. Saá Hernández (CERN)

SwissFEL foresees the possibility to overcompress the bunch in the second bunch compressor to accumulate the energy chirp and the wakefields in the main linac to introduce an energy chirp in the electron bunch. When injected into the undulator beamline this generates a SASE pulse with a full width in bandwidth of about 3% and a pulse energy of about 400 µJ. This operation mode requires preserving the beam quality by correcting beam tilts and dispersion up to second order. This presentation reports on the obtained results from the commissioning of this mode in spring 2019.

TUP072 **Orbital Angular Momentum from SASE**

__J.F. Morgan__, B.W.J. McNeil (USTRAT/SUPA) B.W.J. McNeil, __J.F. Morgan__, B.D. Muratori, P.H. Williams, A. Wolski (Cockcroft Institute) B.D. Muratori, P.H. Williams (STFC/DL/ASTeC) A. Wolski (The University of Liverpool)

Radiation with orbital angular momentum, OAM, has many applications such as in imaging systems and microscopic tweezers. The feasibility of generating light with OAM in a free electron laser, FEL, from amplified shot noise in an electron beam is investigated using the FEL simulation code Puffin. This may allow generation of OAM radiation at shorter wavelengths than currently available, as well as the opportunity to incorporate the technique with other SASE manipulation schemes such as mode locking.

TUP073 **High Repetition-Rate Seeding Schemes Using a Resonator-Amplifier Setup**

__S. Ackermann__, B. Faatz, V. Grattoni, C. Lechner, G. Paraskaki (DESY) G. Geloni, S. Serkez, T. Tanikawa (EuXFEL) W. Hillert (University of Hamburg, Institut für Experimentalphysik)

The spectral and temporal properties of Free-Electron Lasers (FEL) operating on the basis of self-amplified spontaneous emission (SASE) suffer from the stochastic behavior of the start-up process. Several so-called "seeding"-techniques using external radiation fields to overcome this limitation have been proposed and demonstrated. The external seed is usually generated by demanding, high-power laser systems, which are not available with a sufficient laser pulse energy at the high repetition rates of superconducting FEL facilities. In this contribution we discuss several seeding schemes that lower the requirements for the used laser systems, enabling seeded operation at high repetition rates by the means of a resonator-amplifier setup.

TUP074 **FLASH Upgrade for Seeding**

__V. Grattoni__, S. Ackermann, B. Faatz, C. Lechner, G. Paraskaki (DESY) W. Hillert, V. Miltchev (University of Hamburg, Institut für Experimentalphysik)

An upgrade for FLASH, the SASE FEL in Hamburg, is planned after 2020 aiming at fulfilling user requirements like full coherence, variable polarization, and multicolour pulses. In this proceeding, we focus on the FLASH1 beamline that will be operated in seeded mode at a high repetition rate. In particular, we will present and discuss the proposed seeding schemes for delivering FEL radiation with wavelengths from 60 down to 4 nm.

TUP075 **Parameter Constraints for Plasma Accelerator-Driven Seeded Free-Electron Lasers**

__C. Lechner__ (DESY)

Seeded operation of free-electron lasers (FELs) reduces the undulator length required for saturation and at the same time enhances photon pulse properties. To apply these techniques to FELs driven by electron bunches generated in plasma-based accelerators, the electron parameters have to be considered already during the design process. We explore the applicability of various schemes for plasma accelerator-driven, seeded FEL operation.

TUP076 Seeding R&D at sFLASH

***C. Lechner**, S. Ackermann, R.W. Aßmann, B. Faatz, V. Grattoni, I. Hartl, S.D. Hartwell, R. Ivanov, T. Laarmann, T. Lang, M.M. Mohammad Kazemi, G. Paraskaki, A. Przystawik, J. Zheng (DESY) A. Azima, M. Drescher, W. Hillert, V. Miltchev, J. Roßbach (University of Hamburg, Institut für Experimentalphysik) S. Khan (DELTA)*

Free-electron lasers (FELs) based on the self-amplified spontaneous emission (SASE) principle generate photon pulses with typically poor longitudinal coherence. FEL seeding techniques greatly improve longitudinal coherence by initiating FEL amplification in a controlled way using coherent light pulses. The sFLASH experiment installed at the FEL user facility FLASH (at DESY, Hamburg) is dedicated to the study of external seeding techniques. In this contribution, the layout of the sFLASH seeding experiment is presented and an overview of recent experimental results is given.

TUP077 Study of a Seeded Oscillator-Amplifier FEL

***G. Paraskaki**, S. Ackermann, B. Faatz, V. Grattoni, C. Lechner, M. Mehrjoo (DESY) G. Geloni, S. Serkez, T. Tanikawa (EuXFEL) W. Hillert (University of Hamburg, Institut für Experimentalphysik)*

In recent years, there is interest of the FEL community in external-seeding techniques such as the Echo-Enabled Harmonic Generation (EEHG) and the High Gain Harmonic Generation (HGHG). With these techniques, pulses of an improved temporal coherence are generated, but at the same time they are limited by the repetition rates that seed lasers can currently offer with the required pulse energies. A big challenge is to combine the advantages of seeding schemes with high repetition rates. For this purpose, we study a combination of a modulator-oscillator. The oscillator is used at a long wavelength to modulate the electron beam and an amplifier is operated to extract the FEL radiation of the desired harmonic. We present simulation results of a seeded oscillator-amplifier FEL in an HGHG scheme.

TUP078 Impact of Electron Beam Energy Chirp on Seeded FELs

***G. Paraskaki**, S. Ackermann, B. Faatz, V. Grattoni, C. Lechner, J. Zemella (DESY) W. Hillert (University of Hamburg, Institut für Experimentalphysik)*

Seeded FELs enable the generation of fully coherent, transform limited and high brightness FEL pulses, as the start up process is driven by an external coherent light pulse. During the design process of such FELs, it is important to choose carefully the electron beam parameters to guarantee high performance. One of those parameters is the electron beam energy chirp. In this contribution, we show simulation results and we discuss how the electron beam energy chirp affects the final spectrum.

TUP079 Status of the Hard X-Ray Self-Seeding Setup at the European XFEL

***G. Geloni**, S. Karabekyan, D. La Civita, L. Samoylova, S. Serkez, R. Shayduk, H. Sinn, V. Sleziona, M. Vannoni, M. Yakopov (EuXFEL) J.W.J. Anton, S.P. Kearney, D. Shu (ANL) V.D. Blank, S. Terentiev (TISNCM) W. Decking, V. Kocharyan, S. Liu, E. Negodin, E. Saldin, T. Wohlenberg (DESY) X. Dong (European X-Ray Free-Electron Laser Facility GmbH)*

A Hard X-Ray Self-Seeding (HXRSS) setup will be soon commissioned at the European XFEL. It relies on a two-chicanes scheme to deal, in particular, with the high pulse repetition rate of the facility. In this contribution we review the physics choices made at the design stage and the expected performance of the setup. We will also focus on the description of the hardware installations made at the SASE2 line of the European XFEL.

TUP080 Harmonic Off-Axis Seeding at the DELTA Short-Pulse Source

***A. Meyer auf der Heide**, B. Büsing, S. Khan, D. Krieg, C. Mai (DELTA)*

At the 1.5-GeV synchrotron light source DELTA operated by the TU Dortmund University, a short-pulse source employs the coherent harmonic generation (CHG) scheme. Here, a laser pulse interacts with a stored electron bunch forming a microbunching structure to generate ultrashort synchrotron light pulses at harmonics of the laser wavelength. As an upgrade of the short-pulse facility, the echo-enabled harmonic generation (EEHG) scheme shall be implemented, which requires a second laser-electron interaction to yield much higher harmonics compared to CHG. In a study towards twofold laser seeding, the possibility of seeding at undulator harmonics with a crossing angle between laser and electron beam was investigated.

TUP081 Critical Aspects and New Configurations of the FERMI Seed Laser

***M.B. Danailov**, P. Cinquegrana, A.A. Demidovich, G. Kurdi, I. Nikolov, P. Sigalotti (Elettra-Sincrotrone Trieste S.C.p.A.)*

The use of external laser seeding at the FERMI Free Electron Laser (FEL) allowed to demonstrate and then provide to users XUV pulses with remarkably high coherence, wavelength and timing stability. Both single-and double-cascade fresh-bunch High Gain Harmonic Generation (HGHG) schemes have been adopted allowing to cover the spectral range from 4 to 100 nm. The demand for further extending the generated XUV photon energy, as well as the search for exploring new FEL pulse and pump-probe experimental options has driven the evolution of the FERMI seed laser system from its relatively simple original design to a complex double-oscillator double-amplifier architecture. An additional complexity was added to the system in order to provide the UV seed pulses needed by the Echo Enabled Harmonic Generation (EEHG) scheme tested in 2018. We will describe the design and performance of the laser configuration used for the EEHG tests. Some of the critical aspects of HGHG and EEHG seeding and proposed solutions will be discussed.

TUP082 Measurements of the Impact of Seed Laser Chirp on EEHG FEL Spectra

***N.S. Mirian**, E. Allaria, G. De Ninno, W.M. Fawley, G. Gaio, L. Giannessi, G. Penco, P. Rebernik Ribič, C. Spezzani, M. Trovò (Elettra-Sincrotrone Trieste S.C.p.A.) E. Ferrari (EPFL) L. Giannessi (ENEA C.R. Frascati) E. Hemsing (SLAC)*

The echo enabled harmonic generation (EEHG) seeded free electron laser (FEL) configuration allows high harmonic density modulation on a relativistic beam, with a relatively small initial energy modulation. The scheme is based on the double modulation of the same beam with two seed pulses, in two chains of modulators and dispersive sections. Recent experiments carried out at FERMI, the Elettra-FEL user facility, have demonstrated that this scheme allows the conversion of an optical laser to soft-X ray wavelengths in a single harmonic multiplication stage and have shown that the resulting beam is exponentially amplified. We have carried out an analysis of the data available from the experimental sessions on FERMI, to study of the impact of non linear longitudinal phase distortion on the spectrum bandwidth in EEHG. The experimental data are compared to theoretical and numerical models.

TUP083 **Energy Spread Impact on HGHG and EEHG FEL Pulse Energy**

***S. Spampinati**, E. Allaria, L. Giannessi, P. Rebernik Ribič (Elettra-Sincrotrone Trieste S.C.p.A.)*

VUV an X-ray free electron lasers (FELs) require a very bright electron beam. Seeded FEL harmonic generation is particularly sensible to energy spread and slice energy spread can limit the highest harmonic conversion factor at which coherent radiation can be produced. Different cascade schemes can have a different sensibility to the slice energy spread. At FERMI we have evaluated the impact of the slice energy spread on the performance of high gain harmonic generation (HGHG) and of echo enable harmonic generation (EEHG) by measuring the FEL pulse energy as function of the electron beam slice energy spread. The measurements were done at different harmonics. The slice energy spread was varying trough the laser heater located in the LINAC that drive FERMI.

TUP084 **High Repetition Rate and Coherent Free-Electron Laser in the X-rays Range Tailored for Linear Spectroscopy**

***V. Petrillo** (Universita' degli Studi di Milano)*

Fine time-resolved analysis of matter, i.e. spectroscopy and photon scattering in the linear response regime requires a fs-scale pulsed, high repetition rate, fully coherent X-ray sources. A seeded FEL driven by a linac based on super conducting cavities, generating 10^8-10^{10} coherent photons at 2-5 keV with 0.2-1 MHz of repetition rate, can address this need. Three different seeding schemes are described hereafter. The first two are multi-stage cascades upshifting the radiation frequency by a factor 10-30. The X-rays range can be achieved with a seed represented by a coherent flash of extreme ultraviolet. This radiation can be provided either by the High Harmonic Generation of an optical laser or by a FEL Oscillator operating at 12-14 nm. The third scheme is a regenerative amplifier working with X-ray mirrors. The whole chain of the X-ray generation is here described by means of start-to-end simulations.

TUP085 **Angular Dispersion Enabled Microbunching for Coherent EUV and Soft X-Ray FEL Generation in Storage Rings**

***C. Feng** (SARI-CAS) X.F. Wang (SINAP) Z.T. Zhao (SSRF)*

Prebunching is an effective way to reduce the radiation saturation length, improve the longitudinal coherence and output stability of storage ring based FEL. A novel technique which uses angular dispersion to enhance the high harmonic bunching with very small laser-induced energy spread is proposed. This technique can effectively reduce the radiation saturation length without significantly reducing the peak power of the FEL. Numerical simulations demonstrated that this technique can be used for the generation of hundred megawatt-scale level, fully temporal coherent femtosecond EUV and soft X-ray radiation pulses through ten meters undulator based on a diffraction limited storage ring.

TUP086 **Echo-Enabled Harmonic Generation at Shanghai Soft X-Ray FEL Facility**

***C. Feng** (SARI-CAS)*

We present the design studies and experimental results of the echo-enabled harmonic generation experiments that has been recently performed at the Shanghai soft X-ray FEL facility.

TUP087 **S2e Simulations of the Reflection Hard X-Ray Self-Seeding at the SHINE Project**

***T. Liu** (SARI-CAS)*

Due to several potential advantages than transmission type, we have given the proposal of the reflection monochromator based self-seeding scheme and enable the application on the SHINE project. In this manuscript, the specific scheme will be adopted to cover the photon energy of 5-15 keV at undulator line FEL1 and FEL3. S2E simulations will be presented here, illustrating the feasibility of the reflection case at the SHINE project.

TUP088 **Numerical Simulations for Generating Fully Coherent Soft X-Ray Free Electron Lasers With Ultra-Short Wavelength**

***K.S. Zhou** (SARI-CAS)*

For the fully coherent, ultra-short and high power soft X-rays are becoming key instruments in many different research fields, such as biology, chemistry or physics. However, it's hard to generate this kind of advanced light source by the conventional lasers, especially for the soft X-rays with ultra-short wavelength because of no suitable reflectors. The external seeded free electron laser (FEL) is considered as one feasible method. Here, we give an example to generate highly temporal coherent soft X-rays with the wavelength 1 nm by the two-stage cascaded schemes. EEHG scheme is used as the first-stage while the HGHG scheme is used as the second-stage.

TUP090 **Simulations for Implementing the ECHO Scheme in the Soft X-Ray Laser Project at MAX IV**

***M.A. Pop**, F. Curbis, W. Qin, S. Werin (MAX IV Laboratory, Lund University) F. Curbis, S. Werin (SLF) W. Qin (Lund University)*

The Soft X-ray Laser (SXL) currently being studied at MAX IV Laboratory is envisioned to produce coherent radiation in the 1-5 nm wavelength range. In this contribution, we present the results of simulations aimed at adding to the SXL an Echo Enabled Harmonic Generation scheme, which has been shown to increase the coherence of FELs in the Soft X-ray regime. Our work puts special emphasis on accommodating the positive energy chirp of the electron bunch coming out of the MAX IV Linac and on generating sufficient bunching at the high harmonics necessary for covering the full wavelength range.

TUP091 **Start-to-end Simulation of the NSRRC Seeded VUV Free Electron Laser Test Facility**

S.Y. Teng *(NTHU) C.H. Chen, W.K. Lau, A.P. Lee (NSRRC) J. Wu (SLAC)*

A free electron laser (FEL) driven by a 250 MeV high brightness electron linac system has been proposed to generate ultrashort intense coherent radiation in the extreme ultraviolet (EUV) region. It employs the 4th harmonic high-gain high harmonic generation (HGHG) scheme to produce hundreds of MW EUV radiation with wavelength as short as 50 nm from a THU20 twin helical undulator of 20-mm period length. A 200-nm seed laser is used for beam energy modulation in the helical undulator, THU24. Micro-bunching is accomplished by a small chicane before the beam is delivered to THU20. In this study, we perform start-to-end simulation to investigate the operational performance of the test facility.

TUP092 **XFEL Third Harmonic Statistics Measurement at LCLS**

A. Halavanau, *C. Emma, Z. Huang, A.A. Lutman, G. Marcus, T.J. Maxwell, C. Pellegrini (SLAC) M.W. Guetg (DESY)*

We investigate the statistical properties of the 6 keV third harmonic XFEL radiation at 2 keV fundamental photon energy at LCLS. We performed third harmonic self-seeding in the hard X-ray self-seeding chicane and attempt to characterize the attained non-linear third harmonic spectrum. We compare theoretical predictions with numerical simulations and experimental results.

TUD — Tuesday - Late Afternoon

Chair: O.A. Shevchenko (BINP SB RAS)

TUD01 16:15 30 **Generating Orbital Angular Momentum Beams in an FEL Oscillator**

Y.K. Wu, *H. Hao, P. Liu, S.F. Mikhailov, V. Popov, J. Yan (FEL/Duke University) S.V. Benson (JLab)*

Coherent vortices have been generated with several schemes using a single-pass FEL. This work reports the first experimental demonstration of coherent vortice generation using an oscillator FEL. With the storage ring FEL at Duke University, we have established fundamental harmonic FEL lasing in a variety of coherently mixed orbital angular momentum (OAM) modes, with photons in the |l> and |-l> superposition states (l = 1, 2, 3) and with each eigenstate carrying lh OAM. Spatially organized in Laguerre Gaussian modes, stable FEL lasing of these OAM beams has been achieved with reasonable power. Optical techniques have been developed to characterize these beams. The operation of such an OAM FEL paves the way for the generation of OAM gamma-ray beams via Compton scattering.

TUD02 16:45 30 **Application of Infrared FEL Oscillators for Producing Isolated Attosecond X-Ray Pulses via High-Harmonic Generation in Rare Gases**

R. Hajima, *K. Kawase, R. Nagai (QST) Y. Hayakawa, T. Sakai, Y. Sumitomo (LEBRA) T. Miyajima, M. Shimada (KEK) H. Ohgaki, H. Zen (Kyoto University)*

High harmonic generation (HHG) in rare gases is now becoming a common technology to produce attosecond pulses in VUV wavelengths. So far HHG sources have been realized by femtosecond solid-state lasers, not FELs. We propose a FEL-driven HHG source to explore attosecond pulses at photon energies above 1 keV with a MHz-repetition, which is difficult with solid-state lasers. A research program has been launched to establish technologies for the FEL-HHG, which covers generation and characterization of few-cycle IR pulses in a FEL oscillator, stacking of FEL pulses in an external cavity, and a seed laser for stabilization of carrier-envelope phase in a FEL oscillator. In this talk, we present the scheme of FEL-HHG and the status of the research program.

TUD03 17:15 15 **Fine and Hyperfine Structure of FEL Emission Spectra**

V.V. Kubarev, *Ya.V. Getmanov, O.A. Shevchenko (BINP SB RAS) S. Bae, Y.U. Jeong (KAERI)*

The fine structure of the FEL radiation is determined by the coherence between pulses (in systems with several pulses inside an optical resonator), which is usually due to the technical features of the installation. The hyperfine structure of the FEL emission spectrum (optical resonator modes) depends on slow fluctuations in the active medium. This report presents the results of experimental investigations of the fine and hyperfine spectral structures of the NovoFEL and the compact KAERI FEL by the use of optimal instruments - resonance Fabry-Perot interferometers. The very high coherence of NovoFEL with one pulse circulating inside the optical resonator (coherence length is 7 km, relative width of the hyperfine structure lines is 0.5E-8) and the total absence of coherence between two circulating pulses, i.e. fine structure, were measured. Sixty pulses simultaneously circulate inside the KAERI FEL optical resonator, and the coherence length on average covers ten pulses (the coherence length is 1 m, the relative width of the fine structure lines is 10^{-4}). It is planned to measure the hyperfine structure of the KAERI FEL radiation.

TUD04 17:30 15 **Cavity-Based Free-Electron Laser Research and Development: A Joint Argonne National Laboratory and SLAC National Laboratory Collaboration**

G. Marcus, *F.-J. Decker, Z. Huang, Y. Liu, J.P. MacArthur, R.A. Margraf, T.O. Raubenheimer, A. Sakdinawat, T.-F. Tan, D. Zhu (SLAC) L. Assoufid, K. Kim, R.R. Lindberg, X. Shi, D. Shu, Yu. Shvyd'ko, M. White (ANL)*

One solution for producing longitudinally coherent FEL pulses is to store and recirculate the output of an amplifier in an X-ray cavity so that the X-ray pulse can interact with following fresh electron bunches over many passes. The X-ray FEL oscillator (XFELO) and the X-ray regenerative amplifier FEL (XRAFEL) concepts use this technique and rely on the same fundamental ingredients to realize their full capability. Both schemes require a high repetition rate electron beam, an undulator to provide FEL gain, and an X-ray cavity to recirculate and monochromatize the radiation. The shared infrastructure, complementary performance characteristics, and potentially transformative FEL properties of the XFELO and XRAFEL have brought together a joint Argonne National Laboratory (ANL) and SLAC National Laboratory (SLAC) collaboration aimed at enabling these schemes at LCLS-II. We present plans to install a rectangular X-ray cavity in the LCLS-II undulator hall and perform experiments employing 2-bunch copper RF linac accelerated electron beams. This includes performing cavity ring-down measurements and 2-pass gain measurements for both the low-gain XFELO and the high-gain RAFEL schemes.

TUT — Tuesday Tutorial

TUT01 18:00 60

Coherent Spontaneous Superradiance and Stimulated-Superradiant Emission of Bunched Electron Beams

A. Gover *(University of Tel-Aviv, Faculty of Engineering)*

We outline the fundamental processes of coherent radiation emission from a bunched charged particles beam. In contrast to spontaneous emission of radiation from a random electron beam that is proportional to the number of particles N, a pre-bunched electron beam emits spontaneously coherent radiation proportional to N^2 through the process of (spontaneous) superradiance (SP-SR) (in the sense of Dicke's). The SP-SR emission of a bunched electron beam can be even further enhanced by a process of stimulated-superradiance (ST-SR) in the presence of a seed injected radiation field. These coherent radiation emission processes are presented in term of a radiation mode expansion model, applied to general free electron radiation schemes: Optical-Klystron, HGHG, EEHG, and coherent THz sources based on synchrotron radiation, undulator radiation or Smith-Purcell radiation. The general model of coherent spontaneous emission is also extended to the nonlinear regime - Tapering Enhanced Stimulated Superradiance (TESSA), and related to the tapered wiggler section of seed-injected FELs. In X-Ray FELs these processes are convoluted with other effects, but they are guidelines for strategies of wiggler tapering efficiency enhancement.

WEA — Wednesday - Early Morning

Chair: B.E. Carlsten (LANL)

WEA01 09:00 30 **Overview on CW RF Gun Developments for Short Wavelength FELs**

H.J. Qian *(DESY Zeuthen) E. Vogel (DESY)*

Hard X-ray FELs (XFELs) operating with pulsed RF provide unprecedented peak brilliance for scientific research. Operating the accelerators with CW RF improves the flexibility w.r.t. the available time structure for experiments and opens the next frontier of average brilliance. One of the challenges of CW XFELs is the electron source, which requires both CW operation and highest possible beam quality allowing lasing at shortest wavelengths. The CW mode technically constraints the gun acceleration gradient, which is one of the keys to electron source brightness, so R&D is devoted to CW gun improvements since decades. In this contribution, the worldwide development status of CW RF guns, both normal conducting and superconducting, is reviewed.

WEA02 09:30 30 **State-of-the-Art Photocathodes and New Developments**

N.A. Moody*, J. Smedley (LANL) K.L. Jensen (NRL)*

Development of photoemission electron sources for advanced light sources such as X-ray Free Electron Lasers (xFEL), ultra-fast electron diffraction (UED), and low-light sensor applications has motivated a comprehensive engineered-material approach integrating predictive computational physics models, advanced nano-synthesis methods and characterization with in-situ correlated study of photoemission performance and properties. Techniques such as compositionally graded stoichiometry, heterostructured architectures, and quantum features, allowing for enhanced optoelectronic properties. These methods influence the mechanisms of photoemission but have not, until recently, been applied toward photocathode applications. Recent results from a growing collaboration effort involving advanced synthesis, X-ray synchrotron characterization, and modeling efforts show the efficacy of these approaches. Highlights of these studies, including predictions and experimental data, are presented as well as future plans to exploit controlled functionality of nanomaterials for photocathodes and other optoelectronic devices.

WEA03 10:00 15 **Emittance Budget in the Transition Regime Between Linear Emission and Space Charge Dominated Photoemission**

Y. Chen*, M. Krasilnikov, H.J. Qian, F. Stephan (DESY Zeuthen)*

Free electron laser based X-ray facilities require high brightness accelerators which entails minimization of the beam emittance in all planes for a fixed bunch charge. Since the lowest achievable emittance of linac based accelerators is set at the injectors already, emittance optimization at the injector exit needs to carefully budget the contributions from the space charge and rf forces as well as the intrinsic cathode contribution. The optimization of normalized transverse emittance at the Photo Injector Test Facility at DESY in Zeuthen (PITZ) has routinely found the smallest possible emittance for a fixed bunch charge in a so-called transition regime of photoemission. In such a regime, high space charge density of the beam significantly contributes to the phase space formation. Strong space charge fields during the emission process alter the cathode physics thereby changing the emittance budget distribution. Based on an advanced beam dynamics modeling approach, we analyze each decomposed contribution of the measured emittance for understanding the optimization scheme in the transition regime between linear and space charge dominated emission. Obtained results will be presented.

WEA04 10:15 15 **Growing and Characterization of Cs2Te Photocatodes with Different Thicknesses at INFN LASA**

L. Monaco*, P. Michelato, D. Sertore (INFN/LASA) G. Guerini Rocco, C. Pagani (Università degli Studi di Milano & INFN)*

The INFN-LASA group has a long standing experience in the production of cesium telluride photocathodes for high brightness photoinjectors. The well-established recipe relies on the deposition of a typical amount of 10 nm of Te, followed by the Cs deposition until reaching the maximum QE. Nevertheless, for improving the understanding of photocathode properties, we are investigating the effect of Te thickness on the growing process, evaluating photocathode optical properties and quantum efficiency during the growing process and on the final film. These photocathodes will be then operated and analyzed in the real environment of the RF Gun at the PITZ facility in DESY Zeuthen, to estimate their impact on the electron beam properties.

WEB — Wednesday - Late Morning

Chair: A.H. Lumpkin (AAI/ANL)

WEB01 11:00 30 **Identification and Mitigation of Smoke-Ring Effects in Scintillator-Based Electron Beam Images at the European XFEL**

G. Kube, *S. Liu, A.I. Novokshonov, M. Scholz (DESY)*

Standard transverse beam profile measurements at the European XFEL are based on scintillating screen monitors using LYSO:Ce. While it is possible to resolve beam sizes down to a few micrometers with this scintillator, the experience during the XFEL commissioning showed that the measured emittance values were significantly larger than the expected ones. In addition, beam profiles measured at bunch charges of a few hundred pC showed a 'smoke ring' structure. While coherent OTR emission and beam dynamical influence can be excluded, it is assumed that the profile distortions are caused by effects from the scintillator material. Following the experience in high energy physics, a simple model was developed which takes into account quenching effects of excitonic carriers inside a scintillator in a heuristic way. Based on this model, the observed beam profiles can be understood qualitatively. Together with the model description, first comparisons with experimental results will be shown. Possible new scintillator materials suitable for beam profile diagnostics and first test results from beam measurements will be presented.

WEB02 11:30 30 **Wire-Scanners with Sub-Micrometer Resolution: Developments and Measurements**

G.L. Orlandi, *S. Borrelli, Ch. David, E. Ferrari, V. Guzenko, B. Hermann, O. Huerzeler, R. Ischebeck, C. Lombosi, E. Prat (PSI) N. Cefarin, S. Dal Zilio, M. Lazzarino (IOM-CNR) M. Ferianis, G. Penco, M. Veronese (Elettra-Sincrotrone Trieste S.C.p.A.)*

Monitors of the beam transverse profile with ever more demanding spatial resolution and minimal invasivity are required by the FEL community. In order to improve the spatial resolution towards the sub-micrometer limit as well as to decrease the impact on the lasing process, nano-fabricated wire-scanners have been manufactured independently at PSI and FERMI by means of a lithographic technique. Experimental tests carried out at SwissFEL at a low emittance demonstrated the capability of such innovative wire-scanner solutions to resolve beam transverse profiles with a size of 400-500 nm without being affected by any resolution limit. Status and outlook of nano-fabricated wire-scanners will be presented.

WEB03 12:00 30 **Application of Machine Learning to Beam Diagnostics**

E. Fol *(CERN)*

Machine Learning (ML) techniques are widely used in science and industry to discover relevant information and make predictions from data. The application ranges from face recognition to High Energy Physics experiments. Recently, the application of ML has grown also in accelerator physics and in particular in the domain of control and diagnostics. The target is to provide an overview of ML techniques and to indicate beam diagnostics tasks where ML based solutions can be efficiently applied to complement or potentially surpass existing methods. Besides, a summary of recent works will be presented demonstrating promising results for further use of ML concepts in beam diagnostics.

WEB04 12:30 15 **Few-Femtosecond Facility-Wide Synchronization of the European XFEL**

S. Schulz, *M.K. Czwalinna, M. Felber, M. Fenner, C. Gerth, T. Kozak, T. Lamb, B. Lautenschlager, F. Ludwig, U. Mavrič, J.M. Müller, S. Pfeiffer, H. Schlarb, Ch. Schmidt, C. Sydlo, M. Titberidze, F. Zummack (DESY)*

The first facility-wide evaluation of the optical synchronization system at the European XFEL resulted in excellent arrival time stability of the electron bunches at the end of the 2 km long linac, being measured with two individual adjacent femtosecond-resolution bunch arrival time monitors. While each of the monitors is independently linked by a stabilized optical fiber to a master laser oscillator, with one being installed in the injector area and one in the experimental hall, these two reference lasers are tightly synchronized through another few-km long fiber link. Thus, not only the accelerator performance is being benchmarked, but equally the optical synchronization infrastructure itself. Stability on this level can only be achieved by locking the RF for cavity field control to the optical reference and requires an unprecedented synchronization of the master laser oscillator to the main RF oscillator, enabled by a novel RF/optical phase detector. Finally, with the seeders of the experiment's optical lasers synchronized to the master laser oscillator, first experiments at two independent scientific instruments proved an X-ray/optical timing jitter of few tens of femtoseconds.

WEP — Wednesday Poster Session

WEP001 **Development of a THz Oscilloscope for the Detection of Electric Fields in the 1-10 THz Range at the TeraFERMI Beamline**

***E. Roussel**, S. Bielawski, C. Evain, C. Szwaj (PhLAM/CERLA) N. Adhlakha, P. Cinquegrana, S. Di Mitri, P. Di Pietro, A. Perucchi, M. Veronese (Elettra-Sincrotrone Trieste S.C.p.A.)*

The electro-optic sampling (EOS) technique is a well-known method for the detection of electric field in the THz frequency range with a typical resolution of sub-picosecond. It is based on the encoding of the THz signal in a probe laser through a birefringent crystal. We present here the development of a high-resolution single-shot EOS setup based on the spectral-encoding technique using a 1550-nm laser. The setup was installed on the teraFERMI beamline. TeraFERMI is using the THz radiation emitted by electron bunches passing through an Aluminum foil in the beam dump of the FERMI-FEL. Our single-shot EOS setup permits to correlate the THz spectra with the machine setting and the performance of the FEL.

WEP002 **Photonic Time-Stretch Electro-Optic Sampling of Electron Bunches at European XFEL**

***E. Roussel**, S. Bielawski, C. Evain, C. Szwaj (PhLAM/CERLA) C. Gerth, B. Steffen (DESY)*

Electron bunch shape measurement is key in FEL development. However measuring bunch shapes in single-shot is particularly challenging in high repetition machines. In this work, we are testing the so-called photonic time-stretch strategy, which consists in imprinting the bunch electric field onto a chirped laser pulse, and then to "stretch" the output pulse by optical means. As a result, we obtain is a slowed-down "optical replica" of the bunch shape, which can be recorded using a photodiode and GHz-range acquisition board. We will present first tests of this strategy at European XFEL, after the second bunch compressor. These tests are performed in parallel with the existing spectral decoding technique, in order to make a comparative study.

WEP003 **Balanced Optical-Microwave Phase Detector for 800-nm Pulsed Lasers with Sub-Femtosecond Resolution**

***K. Shafak**, A. Berlin, E. Cano Vargas, H.P.H. Cheng, A. Dai, J. Derksen, P. Schiepel (Cycle GmbH) F.X. Kärtner (Deutsches Elektronen Synchrotron (DESY) and Center for Free Electron Science (CFEL))*

Novel light-matter interaction experiments conducted in free-electron lasers, ultrafast electron diffraction instruments and extreme light infrastructures require synchronous operation of microwave sources with femtosecond pulsed lasers. In particular, Ti:sapphire lasers have become the most common near-infrared light source used in these facilities due to their wide-range tunability and their ability to generate ultrashort pulses at around 800-nm optical wavelength. Therefore, a highly sensitive optical-to-microwave phase detector operating at 800 nm is an indispensable tool to synchronize these ubiquitous lasers to the microwave clocks of these facilities. Electro-optic sampling is one approach that has proven to be the most precise in extracting the relative phase noise between microwaves and optical pulse trains. However, their implementation at 800-nm wavelength has been so far limited. Here, we show a balanced optical-microwave phase detector designed for 800-nm operation based on electro-optic sampling. The detector has a timing resolution of 0.01 fs RMS for offset frequencies above 100 Hz and a total noise floor of less than 10 fs RMS integrated from 1 Hz to 1 MHz.

WEP004 **Timing Stability Comparison Study of RF Synthesis Techniques**

***E. Cano Vargas**, F.X. Kärtner (Deutsches Elektronen Synchrotron (DESY) and Center for Free Electron Science (CFEL)) A. Berlin, H.P.H. Cheng, A. Dai, J. Derksen, P. Schiepel, K. Shafak (Cycle GmbH)*

High-precision and low-noise timing transfer from a master clock to different end stations of a free-electron laser (FEL) is an essential task. Timing precisions ranging from few tens of femtoseconds to sub-femtoseconds are required for seeded FELs and attosecond science centers. Mode-locked lasers referenced to RF standards are commonly used as master oscillators, due to their superior stability and timing precision, depicting timing jitter in the attosecond range. In this matter, one of the biggest challenges is to transfer the timing stability of mode-locked lasers to RF sources. Here, we compare and contrast two of the most common techniques used for laser-to-RF synthesis in FEL facilities: (i) RF signal extraction from the optical pulse train using photodiodes, and (ii) VCO-to-laser synchronization. Test setups are built to measure both the absolute phase noise of the generated RF signal and the relative timing jitter with respect to the mode-locked laser. Short-term timing jitter values varying between 10 and 100 fs are achieved for different test setups, while long term timing drift ranging to some hundreds of fs due to environmental influence are observed.

WEP005 **A Post-Undulator X-Band TDS Diagnostics Line for the European XFEL**

***B. Beutner** (DESY)*

Even in pure SASE operation information about the longitudinal phase-space downstream of a FEL undulator line is useful to optimise and tune FEL performance. In advanced FEL schemes like seeding or e.g. fresh slice approaches such data are more important or even essential. Such beamlines utilising X-band transverse deflecting structures are used successfully in other machines like the LCLS. At the European XFEL the time structure, namely the up to 2700 bunches with 4.5 MHz per pulse, impose additional boundary conditions. Such diagnostic lines especially requires an extraction scheme for individual bunches. In this paper we discuss proposed XTDS diagnostic lines for the European XFEL as well as beam optics and operational aspects.

WEP006 **A PolariX TDS for the FLASH2 Beamline**

***F. Christie**, J. Rönsch-Schulenburg, M. Vogt (DESY)*

Transverse Deflecting RF-Structures (TDS) are successfully used for longitudinal diagnostic purposes at many Free-Electron Lasers (FEL) (LCLS, FLASH, EU-XFEL, FERMI). Moreover, by installing a TDS downstream of the FEL undulators and placing the measurement screen in a dispersive section, the temporal photon pulse structure can be estimated, as was demonstrated at LCLS and sFLASH. Here we describe the installation of a variable polarization X-band structure (PolariX TDS) downstream of the FLASH2 undulators. The installation of such a TDS enables longitudinal phase space measurements and photon pulse reconstructions, as well as slice emittance measurements in both planes using the same cavity due to the unique variable polarization of the PolariX TDS.

WEP007 **Usage of the MicroTCA.4 Electronics Platform for Femtosecond Synchronization Systems**
M. Felber, *E.P. Felber, M. Fenner, T. Kozak, T. Lamb, J.M. Müller, K.P. Przygoda, H. Schlarb, S. Schulz, C. Sydlo, M. Titberidze, F. Zummack (DESY)*
At the European XFEL and FLASH at DESY optical synchronization systems are installed providing sub-10 femtosecond electron bunch arrival time stability and laser oscillator synchronization to carry out time-resolved pump-probe experiments with high precision. The synchronization system supplies critical RF stations with short- and long-term phase-stable reference signals for precise RF field detection and control while bunch arrival times are processed in beam-based feedbacks to further time-stabilize the FEL pulses. Experimental lasers are tightly locked to the optical reference using balanced optical cross-correlation. In this paper, we describe the electronic hardware for supervision and real-time control of the optical synchronization system. It comprises various MicroTCA.4 modules including fast digitizers, FPGA processor boards, and drivers for piezos and stepper-motors. Advantages of the system are the high-level of integration, state-of-the-art performance, flexibility, and remote maintainability.

WEP008 **Multi-Beamline Operation at the European XFEL**
L. Fröhlich, *A. Aghababyan, V. Balandin, B. Beutner, F. Brinker, W. Decking, N. Golubeva, O. Hensler, Y. Janik, R. Kammering, H. Kay, T. Limberg, S. Liu, D. Nölle, F. Obier, M. Omet, M. Scholz, T. Wamsat, T. Wilksen, J. Wortmann (DESY)*
The European XFEL uses a unique beam distribution scheme to direct electron bunches to its three undulator lines. The accelerator delivers up to 600 microsecond long bunch trains, out of which parts or individual bunches can be selected for photon production in any of the FELs. This contribution gives a brief overview of the kicker-septum scheme facilitating this and highlights how even complex bunch patterns can easily be configured via the timing system.

WEP009 **Long Term Stability and Slow Feedback Performance at the European XFEL**
R. Kammering *(DESY)*
The European XFEL is now routinely running in user operation since more than two years. Up to 8 longitudinal and 9 transversal slow feedback loops are routinely used to keep the accelerators chosen operation conditions. First tests of comparing the machine 'free-floating' state versus fully fixing all relevant monitoring signals have been carried out and show interesting results. Here we will review the feedback systems in terms of software architecture and conceptual layout but also in respect to feedback and FEL performance.

WEP010 **Femtosecond Laser-to-RF Synchronization and RF Reference Distribution at the European XFEL**
T. Lamb, *M. Felber, T. Kozak, J.M. Müller, H. Schlarb, C. Sydlo, M. Titberidze, F. Zummack (DESY)*
At the European XFEL, optical pulses from a mode-locked laser are distributed in an optical fiber network proving femtosecond stability throughout the accelerator facility. Due to the large number of RF reference clients and because of the expected higher reliability, the 1.3 GHz RF reference signals are distributed by a conventional coaxial RF distribution system. However, the provided ultra-low phase noise 1.3 GHz RF reference signals may drift over time. To remove these drifts, an optical reference module (REFM-OPT) has been developed to detect and correct environmentally induced phase errors of the RF reference. It uses a femtosecond long-term stable laser-to-RF phase detector, based on an integrated Mach-Zehnder amplitude modulator (MZM), to measure and resynchronize the RF phase with respect to the laser pulses from the optical synchronization system with high accuracy. Currently nine REFM-OPTs are permanently operated at the European XFEL, delivering femtosecond stable RF reference signals for critical accelerating field control stations. The operation experience will be reported together with a detailed evaluation of the REFM-OPT performance.

WEP011 **Longitudinal Intra-Train Beam-Based Feedback at FLASH**
B. Lautenschlager, *M.K. Czwalinna, B. Dursun, C. Gerth, S. Pfeiffer, H. Schlarb, Ch. Schmidt (DESY)*
The longitudinal intra-train beam-based feedback has been recommissioned after major upgrades on the synchronization system of the FLASH facility. Those upgrades include: new bunch arrival time monitors (BAM) front-ends and readouts via MicroTCA.4 electronics, upgrade of the optical synchronization system accommodation the latest XFEL design based on PM fibers, and installation of a small broadband normal conducting RF cavity. The cavity is located prior to the first bunch compressor at FLASH and allows energy modulation bunch-by-bunch (1 µs spacing) on the per mille range. Through the energy dependent path length of the succeeding magnetic chicane the cavity is used for ultimate arrival time corrections. Recently the RF cavity operated with a 1 kW pulsed solid-state amplifier was successfully commissioned. First tests have been carried out incorporating the fast cavity as actuator together with SRF stations for larger corrections in our intra-train beam-based feedback pushing now arrival time stabilities towards 5 fs rms and below. The latest results and observed residual instabilities are presented.

WEP012 **Non-Invasive THz Spectrometer with MHz Readout Rate at European XFEL**
N.M. Lockmann, *C. Gerth, B. Schmidt, S. Wesch (DESY)*
The European X-ray Free-Electron Laser located in Hamburg, Germany, generates one of the most powerful and brilliant X-ray laser pulses. Exact knowledge about the longitudinal electron bunch profile is crucial for the operation of the linear accelerator as well as for photon science experiments. A diffraction radiation (DR) beamline at final electron beam energies of up to 17.5 GeV has been installed downstream of the main linac just before

the switchyard to the three FEL undulator beamlines. The spectral intensity of the DR in the THz and infrared regime is monitored by the 4-staged grating spectrometer CRISP and allows non-invasive bunch length characterization based on form factor measurements down to a few micrometers. As the readout and signal shaping electronics of the spectrometer have been modified for MHz readout rates, the longitudinal bunch profile of all bunches inside the bunch train can be characterized non-invasively and simultaneously to FEL operation. In this contribution, form factor measurements along the bunch train will be described and presented as well as the resulting reconstructed current profiles.

`WEP013` **Fast Kicker System for European XFEL Beam Distribution**

F. Obier, *W. Decking, M. Hüning (DESY)*

A special feature of the European XFEL X-ray laser is the possibility to distribute the electron bunches of one beam pulse to different free-electron laser (FEL) beam-lines. This is achieved through a combination of kickers and a Lambertson DC septum. The integration of a beam abort dump allows a flexible selection of the bunch pattern at the FEL experiment, while the superconducting linear accelerator operates with constant beam loading. The driver linac of the FEL can deliver up to 600 µs long bunch trains with a repetition rate of 10 Hz and a maximum energy of 17.5 GeV. The FEL process poses very strict requirements on the stability of the beam position and hence on all upstream magnets. It was therefore decided to split the beam distribution system into two kicker systems, long pulse kickers with very stable amplitude (flat-top) and relatively slow pulses and fast stripline kickers with moderate stability but very fast pulses. This contribution gives a brief overview of the fast kicker system.

`WEP014` **Long Pulse Kicker System for European XFEL Beam Distribution**

F. Obier, *W. Decking, M. Hüning (DESY)*

A special feature of the European XFEL X-ray laser is the possibility to distribute the electron bunches of one beam pulse to different free-electron laser (FEL) beam-lines. This is achieved through a combination of kickers and a Lambertson DC septum. The integration of a beam abort dump allows a flexible selection of the bunch pattern at the FEL experiment, while the superconducting linear accelerator operates with constant beam loading. The driver linac of the FEL can deliver up to 600 µs long bunch trains with a repetition rate of 10 Hz and a maximum energy of 17.5 GeV. The FEL process poses very strict requirements on the stability of the beam position and hence on all upstream magnets. It was therefore decided to split the beam distribution system into two kicker systems, long pulse kickers with very stable amplitude (flat-top) and relatively slow pulses and fast stripline kickers with moderate stability but very fast pulses. This contribution gives a brief overview of the long pulse kicker system.

`WEP015` **Electro-Optical Bunch Length Detection at the EuXFEL**

B. Steffen, *M.K. Czwalinna, C. Gerth (DESY)*

The electro-optical bunch length detection systems based on electro-optic spectral decoding have been installed and are being commissioned at the European XFEL. The systems are capable of recording individual longitudinal bunch profiles with sub-picosecond resolution at a bunch repetition rate 1.13 MHz. Bunch lengths and arrival times of entire bunch trains with single-bunch resolution have been measured as well as jitter and drifts for consecutive bunch trains. In this paper, we present first measurement results for the electro-optical detection system located after the second bunch compressor. A preliminary comparison with data from the bunch arrival-time monitor shows good agreement.

`WEP016` **Precise Laser-to-RF Synchronization of Photocathode Lasers**

M. Titberidze, *M. Felber, T. Kozak, T. Lamb, J.M. Müller, H. Schlarb, S. Schulz, C. Sydlo, F. Zummack (DESY)*

RF photo-injectors are used in various large, mid and small-scale accelerator facilities such as X-ray Free Electron Lasers (XFELs), external injection-based laser-driven plasma accelerators (LPAs) and ultrafast electron diffraction (UED) sources. Many of these facilities require a high precision synchronization of photo-injector laser system, either because of beam dynamics reasons or the photo-injector directly impacting pump-probe experiments carried out to studying physical processes on femtosecond timescales. It is thus crucial to achieve synchronizations in the order of 10 fs rms or below between the photocathode laser and the RF source driving the RF gun. In this paper, we present the laser-to-RF synchronization setup employed to lock the commercial near-infrared (NIR) photocathode laser oscillator to 2.9979 GHz RF source. Together with the first results achieving less than 20 fs rms timing jitter in the measurement bandwidth from 10 Hz up to 1 MHz, we describe an advanced synchronization setup as a future upgrade, promising even lower timing jitter and most importantly the long-term timing drift stability.

`WEP017` **Pulse and Field-Resolved Photon Diagnostics at a Superradiant THz User Facility**

M. Chen, *N. Awari, M. Bawatna, J.-C. Deinert, S. Germanskiy, I.E. Ilyakov, S. Kovalev, S. Kovalev, Zhe. Wang (HZDR) M. Gensch (Technische Universität Berlin) M. Gensch (DLR)*

Multi-color pump-probe techniques utilizing modern accelerator-based 4th generation light sources such as THz facilities have become important science drivers over the past 10 years. In this type of experiments the precise knowledge of the properties of the involved accelerator-based light pulses crucially determines the achievable sensitivity and temporal resolution. In this work we demonstrate and discuss the powerful role pulse and field-resolved detection of superradiant THz pulses can play for improving the precision of THz pump femtosecond laser probe experiments at superradiant THz facilities in particular and at 4th generation light sources in general. The developed diagnostic scheme provides realtime information on the properties of individual pulses from multiple accelerator based THz sources operated at 100 KHz repetition rate and opens a robutst way for sub femtosecond timing. Correlation of the amplitude and phase of the pulses emitted from different super-radiant THz sources furthermore provides insides into the properties of the driving electron bunches and is of general interest for the ultra-fast diagnostics at 4th generation light sources.

WEP018 **Single-Shot Arrival Time Monitor Based on XUV-THz Conversion**

I.E. Ilyakov, *J.-C. Deinert, S. Kovalev (HZDR) N. Agarwal, R. Carley, L. Le Guyader, J. Liu, A. Scherz, A.A. Yaroslavtsev (EuXFEL) L. Foglia, G. Kurdi, R. Mincigrucci, E. Principi (Elettra-Sincrotrone Trieste S.C.p.A.) M. Gensch (Technische Universität Berlin) M. Gensch (DLR) T. Kampfrath (FUB) T. Kampfrath (FHI)*

A new arrival-time detection technique for femtosecond XUV pulses generated by a FEL is experimentally demonstrated. The experiments were done at the EIS-TIMEX beamline, FERMI, Italy. The technique is based on a single-shot measurement of THz pulses received from an XUV-THz convertor. The single-shot arrival-time measurement is done by the electro-optic spectral-encoding technique. The conversion between XUV and THz bands is a new unexplored area of photon science and opens up new avenues for versatile photon diagnostic concepts. Using the proposed technique, timing between the FEL and external laser systems of better than 20 fs can be achieved. The method is easily implemented, does not demand high XUV intensities and can be employed at high repetition rate facilities such as the European XFEL.

WEP019 **Concept of a Novel High-Bandwidth Arrival Time Monitor for Very Low Charges as a Part of the All-Optical Synchronization Systems at XFEL and FLASH**

A. Penirschke *(THM) W. Ackermann (TEMF, TU Darmstadt) M.K. Czwalinna, H. Schlarb (DESY)*

Numerous advanced applications of X-ray free-electron lasers require pulse durations and time resolutions in the order of only a few femtoseconds or better. The generation of these pulses to be used in time-resolved experiments require synchronization techniques that can simultaneously lock all necessary components to a precision in the range of 1 fs only. To improve the experimental conditions at existing facilities and enable future development of seeded FELs, a new all-optical synchronization system at FLASH and XFEL was implemented, which is based on pulsed optical signals rather than electronic RF signals. In collaboration with DESY, Hamburg the all-optical synchronization system is used to ensure a timing stability on the 10 fs scale at XFEL. For a future ultra-low charge operation mode down to 1 pC at XFEL an overall synchronization of (5+1)fs r.m.s. or better is necessary. This contribution presents a new concept for a ultra-wideband pick-up structure for beampipe diameters down to 10 mm for frequencies up to 100 GHz or higher and at the same time providing sufficient output signal for the attached EOMs.

WEP020 **Thomson Scattering of Intense Laser Pulses from Beams and Plasmas**

A. Haj Yhya *(Ariel University)*

Thomson scattering is a very powerful diagnostic, which is applied at nearly every magnetic confinement device. Depending on the experimental conditions different plasma parameters can be diagnosed. About Thomson scattering in plasma, when the wavelength is much smaller then the plasma debye length, the total scattered power is obtained by an incoherent summation over the scattered powers of the individual electrons. The scattering spectrum in this case is a flection of the electron velocity distribution, from which local values for the electron temperature and density can be derived. In case the wavelength is larger then the debye length, Thomson scattering can yield information on the ion velocity distribution and collective behavior of the electrons, as is the case with density fluctuation. About Thomson scattering in electron beams, when the wavelength of the iclud laser is much larger then h/mc (Compton wavelength of electron), the total scattered is coherent, and when the wavelength is smaller then h/mc, the scattering is non-coherent and knocking-out of electrons.

WEP021 **Architecture of the Synchronization, Delay and Timing of the Multifunctional FERMI Seed Laser System**

P. Sigalotti, *P. Cinquegrana, M.B. Danailov, A.A. Demidovich, G. Kurdi, I. Nikolov, M. Veronese (Elettra-Sincrotrone Trieste S.C.p.A.)*

In order to ensure the optimal seeding for both FEL1 and FEL2, the Seed Laser operates with two OPAs, each of them is pumped by its dedicated regenerative amplifier. Each amplifier is allocated to one of the FEL lines, therefore one amplifier always seeds the running FEL line, while we can transport the pulses of the other to the experimental hall for pump-probe experiments, also we can provide a second seed pulse as required by the novel EEHG seeding scheme or for Electro Optical Sampling diagnostics. Right now the two amplifiers share a common oscillator. This allows to minimize the timing jitter, but at the expense of the wavelength tunability. In order to have the maximum flexibility we are installing a second Ti:Sa oscillator, therefore the two amplifiers will be independently tunable in terms of wavelength and bandwidth. We will present the synchronization layout, designed to keep the temporal jitter between the two oscillators as low as possible. We will present also our efforts in improving the synchronization capability of the new oscillator, evaluating the performance of piezo actuators, and the selected Balanced Optical Cross Correlation scheme.

WEP022 **Fabrication and Performance of the Digital Low-Level RF Control System for the Superconducting Cavity**

C.L. Lao, *P. Li (CAEP/IAE) L.W. Feng (PKU)*

CAEP (the China Academy of Engineering Physics) has developed a high average power THz radiation facility based on the FEL technology. A 1.3 GHz RF superconducting cavity is used to achieve 6~8 MeV energy growth. In order to regulate the amplitude and the phase of the accelerating voltage inside the superconducting cavity, a digital LLRF (low-level radio-frequency) control system based on FPGA (field programmable gate array) technology was developed. This article mainly focuses on the fabrication and performance of the LLRF system, some test experiments have also been done and shows that the LLRF system works well and meets the design requirements.

WEP023 **Kicker Pulse Generation Using Parameter Fitting Method for Continuous Bunch Trains**
J. Wang, *P. Li, D.X. Xiao (CAEP/IAE)*
A kicker system was used for intra-bunch-train feedback to induce trajectory variations in the train. It is difficult to generate a train of square pulses with flat top of several 10s picosecond and with bunch spacing in several nanosecond. For the bandwidth of the signal generation and RF amplifer is limited. In this paper, parameter fitting method to generate arbitrary kicks to each bunch not to disturb neighbouring bunches.

WEP024 **1.3 GHz Solid State Power Amplifier for the Buncher in CTFEL Facility**
T.H. He, *C.L. Lao, P. Li, X. Luo, L.J. Shan, K. Zhou (CAEP/IAE)*
The THz Free Electron Laser facility (CAEP THz FEL, CTFEL) of the China Academy of Engineering Physics uses high quality electron beams to generate high average power terahertz radiations. A 1.3 GHz RF buncher is used in front of the superconducting linear accelerator of the CTFEL facility to improve the electron beams quality. The RF buncher is driven by a solid state power amplifier (SSPA), and the SSPA is feedback controlled by a low level RF (LLRF) control system to ensure the high stability of the amplitude and phase of the bunching field in the buncher cavity. The SSPA operates at 1.3 GHz and outputs 0 to 5 kW of continuous wave power. This paper mainly introduces the principle and composition of the SSPA, and presents some experiments on the RF buncher driven by the SSPA.

WEP025 **The Design of Optical Synchronization Between THz Laser and Mode-Locked Ti: Sapphire Laser**
L.B. Li, *X. Jin, C.L. Lao, M. Li, P. Li, J. Wang, X. Yang (CAEP/IAE)*
Synchronization between mode-locked femtosecond laser and a terahertz laser is needed for China Academy of Engineering Physics Terahertz Free Electron Laser (CTFEL) to do some pump-probe experiments. An optical timing system which is based on optical cross-correlator will be designed for the CTFEL to provide this synchronization. Also, it will be expected to provide the sub-100 fs timing jitter between THz-FEL and a mode-locked Ti: Sapphire femtosecond laser. The Ti: Sapphire femtosecond laser will be used for the master laser oscillator (MLO), which will provide the precise timing information to the entire facility for synchronization.

WEP026 **Geometry Optimization of a 3.5-Cell SRF Gun Cavity at ELBE Based on Beam Dynamics**
K. Zhou, *P. Li (CAEP/IAE) A. Arnold, S. Ma, J. Teichert, R. Xiang (HZDR)*
A new superconducting radio-frequency (SRF) electron gun is developed at HZDR ELBE source. To optimize the geometry of the 3.5-cell SRF gun cavity, the distributions of the electromagnetic fields and the output electron beam qualities with different geometric models are investigated and compared in this paper. The simulation results show by increasing the length of the half cell and decrease the length of the first Tesla cell, we can obtain higher electric field in the first half cell and better output beam parameters, which, however, will also lead to a higher $Emax/E_{acc}$ and $Bmax/E_{acc}$.

WEP027 **A Fast and Accurate Method to Shim Undulator Using Multi-Objective GA**
L.G. Yan, *P. Li (CAEP/IAE)*
GA (Genetic Algorithm) is one of the most excellent methods to search the optimal solution for a problem, which has been applied to solve various problems. It is hard to estimate shim applied on raw undulator precisely. There are many methods have been developed to solve the problem. In this proceeding, we proposed a fast and accurate method to conclude the shim using multi-objective GA. The code was written with the language of python and based on package pyevolve. A multi-objective evaluation function was set, and multi-objective optimization also can be implemented. The evolution time is reduced by setting optimal evolution parameters. To demonstrate the method, we also finished some test on a short U38. As a result, it can be achieved only by shimming twice that all the parameters of trajectory center offset, peak-to-peak error and phase error satisfied the requirements.

WEP028 **Design of the Beam Switching Section for Shanghai Soft X-Ray Free Electron Laser User Facility**
S. Chen *(SINAP) H.X. Deng (SARI-CAS) R. Wang (SSRF)*
The Shanghai Soft X-Ray FEL test facility will be upgraded to be a user facility. Energy will be increased and one more undulator line will be installed besides the original one. For simultaneously operation of the two undulator lines, a beam switching section with fast kickers will be added between the linac and the undulator lines. In this work, the design work and recent progress will be described.

WEP029 **Design of the Beam Switchyard for Shine |—| a Hard X-Ray FEL Facility**
S. Chen, *R. Zhao (SINAP) M. Gu, R. Wang (SSRF) D. Wang (SARI-CAS)*
For the SHINE project, the CW electron beam generated by a superconducting linear accelerator should feed at least three undulator lines simultaneously. For this purpose, there should be a beam switchyard with fast kickers between the linac and undulator lines. In this work, the physics design of this beam switchyard will be described.

WEP030 **All-Fiber Photonic, Ultralow-Noise, Robust Optical and Microwave Signal Generators for FELs and UED**
J. Kim, *I.J. Jeon, D. Kim, D. Kwon (KAIST)*
Optical timing and synchronization is becoming a more important and essential element for ultrafast X-ray and electron science. As a result, compact, ultralow-noise, mechanically robust and long-term stable optical and microwave signal generators are highly desirable for future XFELs and UEDs. Here we show that the combination of mode-locked fiber laser and fiber delay-based stabilization method enables the generation of ultralow-noise optical and microwave signals. We show that all-PM fiber lasers can provide excellent mechanical robustness: stable laser operation over >1 hour is maintained even in continuous 1.5 g vibrations. Using a compactly packaged fiber delay as the timing reference, we could stabilize the repetition-rate phase noise of mode-locked lasers down to -100 dBc/Hz and -160 dBc/Hz at 1 Hz and 10 kHz offset frequency, respectively, at 1 GHz carrier, which

corresponds to only 1.4 fs rms absolute timing jitter [1 Hz - 100 kHz]. With DDS-based electronics, low-noise and agile microwave frequency synthesizer was also realized. This new class of photonic signal generator will be suitable for master oscillators in various accelerator-based light sources.

WEP031 **Timing Synchronization Activities for Drift-Free Operation of Ultrafast Electron Diffraction System at KAERI**
J. Shin, *J. Kim (KAIST) I.H. Baek, Y.U. Jeong, H.W. Kim, K. Oang, S. Park (KAERI)*
Precise timing synchronization of an ultrafast electron diffraction facility is essential requirement for femtosecond resolution structure analysis. Recent studies of THz-based electron deflectors have enabled the timing drift measurement between ultrafast electrons and an optical pump beam with few femtosecond resolution. In this work, we will introduce timing synchronization activities to suppress the drift of an electron beam. As timing drift of the electron beam originates from every sub-element, each timing drift contribution from RF transfer, RF-to-optical synchronization, and optical amplification is measured. Timing drift of RF transfer through coaxial cable, which exposed to temperature fluctuation, is actively stabilized from 2 ps to 50 fs by active feedback loop. Further additive drift from RF-to-optical synchronization is maintained below 100 fs. Also optical drift due to the regenerative amplifier, measured by optical correlator, is maintained below 20 fs over an hour. This work allows ultrafast electron diffraction system to operate with less drift correction procedure and increased user availability.

WEP032 **Temporal Diagnostics of X-Ray Free Electron Laser Pulse by Using a Narrow Slotted Foil**
I.H. Nam, *M.H. Cho, H.-S. Kang, C. Kim, G. Kim, C.-K. Min, D.H. Na, C.H. Shim, H. Yang (PAL)*
The pulse duration of X-ray from free electron laser (FEL) is from few tens of femtosecond to few femtosecond scale, which is difficult to be directly measured. We show the preliminary results of measurement of the X-ray pulse duration at Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) using a narrow line slotted foil scanning method. This emittance spoiling foil method is used to vary the pulse duration or generate two pulses. At the center of the bunch compressor, the dispersed beam has a linear time-energy correlation. Thus, the temporal profile of the X-ray can be measured by scanning the position with a very narrow slit. The pulse duration and spectrogram of hard X-ray FEL using the single shot spectrometer can be measured. This method is a very simple and effective temporal diagnostic tool of X-ray pulse for XFEL user facilities.

WEP033 **Diagnostics for the SXL at MAX IV**
E. Mansten *(MAX IV Laboratory, Lund University)*
Diagnostics for the SXL at MAX IV.

WEP034 **An Algorithm for Spectral Analysis of FEL Radiation**
M.A. Pop *(MAX IV Laboratory, Lund University) E. Allaria (Elettra-Sincrotrone Trieste S.C.p.A.)*
By analyzing the spectral content of FEL electron radiation, we can gain new information about the properties of the electron bunch and on the FEL process itself. In this work, we present a peak detection algorithm and its capabilities in characterizing the spectra of seeded FEL.

WEP035 **NIR Spectrometer for Bunch-Resolved, Non-Destructive Studies of Microbunching at European XFEL**
S. Fahlström, *M. Hamberg (Uppsala University) C. Gerth, N.M. Lockmann, B. Steffen (DESY)*
At the European X-ray Free Electron Laser high brilliance femtosecond FEL radiation pulses are generated for user experiments. For this to be achieved electron bunches must be reliably produced within very tight tolerances. In order to investigate the presence of micro-bunching, i.e. charge density variation along the electron bunch with features in the micron range, a prism-based NIR spectrometer with an InGaAs sensor, sensitive in the range 900-1700 nm was installed. The spectrometer utilizes diffraction radiation (DR) generated at electron beam energies of up to 17.5 GeV. The MHz repetition rate needed for bunch resolved measurements is made possible by the KALYPSO line detector system, providing a read out rate of up to 2.7 MHz. We present the first findings from commissioning of the NIR spectrometer, and measurements on the impact of the laser heater system for various bunch compression settings, in terms of amplitude and bunch-to-bunch variance of the NIR spectra as well as FEL pulse energy.

WEP036 **The PolariX-TDS Project: Bead-Pull Measurements and High-Power Test on the Prototype**
P. Craievich, *M. Bopp, H.-H. Braun, R. Ganter, M. Kleeb, F. Marcellini, M. Pedrozzi, E. Prat, S. Reiche (PSI) R.W. Aßmann, F. Christie, R.T.P. D'Arcy, U. Dorda, M. Foese, M. Hüning, R. Jonas, O. Krebs, S. Lederer, V. Libov, B. Marchetti, D. Marx, J. Osterhoff, M. Reukauff, H. Schlarb, G. Tews, M. Vogt (DESY) N. Catalán Lasheras, A. Grudiev, G. McMonagle, W.L. Millar, S. Pitman, K.T. Szypula, W. Wuensch, V. del Pozo Romano (CERN) W.L. Millar (Cockcroft Institute)*
A collaboration between DESY, PSI and CERN has been established to develop and build an advanced modular X-band transverse deflection structure (TDS) system with the new feature of providing variable polarization of the deflecting force. The prototype of the novel X-band TDS, the Polarizable X-band (PolariX) TDS, was fabricated at PSI following the high-precision tuning-free production process developed for the C-band Linac of the SwissFEL project. Bead-pull RF measurements were also performed at PSI to also verify that the polarization of the dipole fields does not have any rotation along the structure. The high-power test was performed at CERN and now the TDS is at DESY and will be installed in FLASHForward where the first streaking experience with beam will be accomplished. We summarize in this paper the status of the project, the results of the bead-pull measurements and high power test.

WEP037 **RF Jitters and Electron Beam Stabilities in the SwissFEL Linac**
P. Craievich, *Z.G. Geng, R. Zennaro (PSI)*
The X-ray FEL machine SwissFEL at the Paul Scherrer Institut in Switzerland is commissioned and transiting to user operation smoothly. FEL operation requires stringent requirements for the beam stability at the linac

output, such as the electron bunch arrival time, peak current and average energy. Among other things, a highly stable RF system is required to guarantee the beam stabilities. The SwissFEL RF system is designed based on the state-of-the-art technologies that have allowed achieving excellent RF stabilities. The RF amplitude and phase jitters are analyzed and compared with the RF measurements performed at SwissFEL linac. Furthermore, a model is developed in order to compare the estimated and measured electron beam stabilities. This paper summarizes the results obtained for the RF and electron beam stabilities.

WEP038 **Commissioning and Stability Studies of SwissFEL Bunches Separation System**

M. Paraliev, *S. Dordevic, R. Ganter, C.H. Gough, N. Hiller, R.A. Krempaská, D. Voulot (PSI)*

SwissFEL is a linear electron accelerator based, fourth generation light source at the Paul Scherrer Institute, Switzerland. It is a user oriented facility capable of producing short, high brightness X-ray pulses covering the spectral range from 1 to 50 Å. SwissFEL is designed to run in two electron bunches mode in order to serve simultaneously two experimental beam line stations (hard and soft X-ray one) at its full repetition rate. Two closely spaced (28 ns) electron bunches are accelerated in one RF macro pulse up to 3 GeV. A high stability resonant kicker system and a Lambertson septum magnet are used to separate the bunches and to send them to their respective beam lines. With the advancement of the construction of the second beam line (Athos) the beam separation system was successfully commissioned. In order to confirm that the beam separation process is fully transparent a stability study of the electron beam and the free electron laser in the main beam line (Aramis) was done

WEP039 **Stripline BPM Simulation, Design, Manufacturing, and Testing in THz FEL Facility in NSRRC**

H.P. Hsueh, *M.C. Chou, J.-Y. Hwang, W.K. Lau, A.P. Lee (NSRRC)*

A tera-hertz free electron laser (THz FEL) source has been built in National Synchrotron Radiation Research Center (NSRRC) in Hsinchu City, Taiwan. The accurate electron beam path has not been measured yet. A set of stripline beam position monitors (BPM) has been designed and are under construction. SUPERFISH 2D simulation software has been used to match the even mode impedance of the stripline structure to fifty Ohms impedance with connected electronics. Two sets will be installed inside two quadrupole magnets to save space. The stripline BPM will be measured with time-domain reflectometry (TDR) to confirm the design and simulation. They will be installed and tested with beam. Measured beam position results will be presented. It will help to optimize the beam path and measure the actual beam energy.

WEP041 **Feasibility of Single-Shot Microbunching Diagnostics for a Pre-Bunched Beam at 266 nm**

A.H. Lumpkin *(AAI/ANL) D.W. Rule (Private Address)*

Co-propagating a relativistic electron beam and a high-power laser pulse through a short undulator (modulator) provides an energy modulation which can be converted to a periodic longitudinal density modulation (or microbunching) via the R56 term of a chicane. Such pre-bunching of a beam at the resonant wavelength and the harmonics of a subsequent free-electron laser (FEL) amplifier seeds the process and results in improved gain. We describe potential characterizations of the resulting microbunched electron beams using coherent optical transition radiation (COTR) imaging techniques for transverse size (50 micron), divergence (sub-mrad), trajectory angle (0.1 mrad), spectrum (few nm), and pulse length (sub-ps). The transverse spatial alignment is provided with near-field imaging and the angular alignment is done with far-field imaging and two-foil COTR interferometry (COTRI). Analytical model results for a 266-nm wavelength COTRI case with a 10% microbunching fraction will be presented. COTR gains of 7 million were calculated for an initial charge of 300 pC which enables splitting the optical signal for single-shot measurements of all the cited parameters.

WEP042 **Observations of Short-Range Wakefield Effects in TESLA-Type SCRF Cavities**

A.H. Lumpkin, *D.R. Edstrom, J. Ruan, R.M. Thurman-Keup (Fermilab)*

The accelerators for high power X-ray free-electron laser (FEL) facilities such as the European XFEL and planned LCLS-II X-ray FEL are employing TESLA-type SCRF cavities. Beam propagation off axis in these cavities can result in both short-range and long-range transverse wakefields which can lead to emittance dilution within the micropulses and macropulses, respectively. The Fermilab Accelerator Science and Technology (FAST) facility has a unique configuration of a photocathode RF gun beam injecting two TESLA-type single cavities (CC1 and CC2) in series prior to the cryomodule. To investigate short-range wakefield effects, we used a vertical corrector between these two cavities to steer the beam off axis at an angle into CC2. A Hamamatsu synchroscan streak camera viewing a downstream OTR screen provided an image of y-t effects within the micropulses with resolutions of ~10-micron spatial and 2-ps temporal. At 500 pC/b, 50 b, and 4 mrad off-axis steering, we observed an ~100-micron head-tail centroid shift in the streak camera image. This centroid shift is consistent with a calculated short-range wakefield effect. Additional results for kick-angle compensation will be presented.

WEP043 **Multi-Energy Operation Analysis in an SRF Linac Based on off-Frequency Detune Method**

Z. Zhang, *C. Adolphsen, Y. Ding, T.O. Raubenheimer (SLAC)*

The free-electron laser facilities driven by a superconducting radio-frequency (SRF) linac provide high-repetition-rate electron beam, which makes it feasible to feed multiple undulator lines at the same time. In this paper, we study a method of controlling the beam energy of multiple electron bunches by off-frequency detuning of the SRF linac. The required full range of the frequency detune for independent control of each beam energy is about the electron beam repetition rate. The initial phases of the detuned acceleration sections can be optimized to make full use of the SRF linac energy capability. We adopt the LCLS-II-HE configuration as an example to present the detailed analysis for this method.

WEP044 **Circular Dichroism of Electrons Photoemitted From an Emitter Array of Au Nanospirals**

H. Ye *(Deutsches Elektronen Synchrotron (DESY) and Center for Free Electron Science (CFEL))*

Surface plasmon polaritons (SPPs) at the interface between a metal and a dielectric material lead to the field component normal to the surface being enhanced near the surface. For planar Archimedean nanospirals, due to plasmonic incoupling and outcoupling by chiral nanostructures, photoinduced SPPs affect the trajectory of the photoemitted electrons, thereby opening up new possibilities for electron bunch modulation upon photoemission and near-field acceleration. In this study, we have investigated chiral plasmonically enhanced photoemission from an array of left-handed Au nanospirals using a velocity-map-imaging (VMI) spectrometer. The transverse velocity distributions of the photoemitted electrons were recorded under both right-handed (RHC) and left-handed (LHC) circular polarizations of 45-fs laser pulses. Approximately 4% difference of the electron counts in the center of subtracted velocity-map images from RHC to LHC has been observed. The RHC polarization, which focuses the electric field in the center of left-handed nanospirals, results in more emitted electrons in the center of velocity-map images, indicating less transverse energy spread, compared to LHC polarization.

WEP045 **Status of the Klystrons for the European XFEL after Commissioning and First User Operation Phase**

M. Bousonville*, A. Cherepenko, S. Choroba, H.-J. Eckoldt, T. Grevsmühl, J. Hartung, V.V. Katalev, K. Machau, P. Morozov, V. Vogel (Fogel), B. Yildirim (DESY)*

At present 26 RF stations for the European XFEL are in operation. Each of the RF stations consists of a HV modulator located on the DESY campus, up to 1600 m long 10 kV HV cables that connect the modulators and the HV pulse transformers located in the underground tunnel, the horizontal multi-beam klystron (MBK), and an air filled waveguide distribution system (WG) between the klystron and the cavities input couplers. The klystrons can produce RF power up to 10 MW, 1.5 ms RF pulse length and 10 Hz repetition rate. Two RF stations of the injector have already achieved about 30,000 hours of operation, RF stations of the XFEL bunch compressor area have operated up to 20,000 hours and the klystrons in the XFEL main linac already have about 18,000 hours of operation. To increase the lifetime of the klystrons we are using a fast protection system (KLM) that is in routine operation since 2018 in addition to the common interlock system. In this article we will give a summary of the present klystrons operation status including the number of HV and RF arcs in the klystrons and in the WG system and operation statistics for the high power RF part of machine.

WEP046 **The European XFEL Photocathode Laser**

A. Choudhuri*, I. Hartl, C. Li, C. Mohr, J.M. Müller, S. Pfeiffer, L. Winkelmann (DESY)*

We present the Yb:fiber, Nd:YVO4 laser used to generate electrons from the RF photocathode gun at the European XFEL. The laser provides deep UV output pulses in 600 µs bursts with variable internal repetition rate (564 kHz to 4.5 MHz). Due to its robust architecture (mode-locked and synchronized fiber oscillator, Yb:fiber amplifiers and Nd:YVO4 gain blocks), the laser has operated with >99% uptime since January 2017. Using this laser, the XFEL reported energies of 17.5 GeV in July 2018, and simultaneous multi-mJ lasing in its three SASE beamlines. The laser offers two parallel outputs (10^{64} nm) with single pulse energies of >10^{0} µJ and 11 ps width (FWHM). One output is converted to deep UV with efficiencies > 25%, and the second is used as a laser heater to reduce microbunching instabilities to increase SASE efficiency. Several state-of-art laser controls were implemented, including feed-forward algorithm to flatten electron charge along the bunch, active beam stabilization with < ±10 µm jitter at the photocathode, state machines for hands-off end-user operation, and temporal pulse synchronization and drift compensation to the timing jigger of the electron bunches to less than 45 fs.

WEP047 **Update on the Photocathode Lifetime at FLASH and European XFEL**

S. Lederer*, S. Schreiber (DESY) L. Monaco, D. Sertore (INFN/LASA)*

The photoinjectors of FLASH and the European XFEL at DESY (Hamburg, Germany) are operated by laser driven RF-guns. In both facilities Cs2Te photocathodes are successfully used. In this paper we give an update on the lifetime, quantum efficiency (QE) and dark current of the photocathodes used over the last years. At FLASH cathode #73.3 was operated for a record lifetime of 1413 days and was replaced December 2018 by cathode #105.2. At the European XFEL cathode #680.1 is in operation since December 2015, for more than 1250 days up to now.

WEP048 **FLASH Photoinjector Laser Systems**

S. Schreiber*, C. Grün, K. Klose, J. Rönsch-Schulenburg, B. Steffen (DESY)*

The free-electron laser facility FLASH at DESY (Hamburg, Germany) operates two undulator beamlines simultaneously for FEL operation and a third for plasma acceleration experiments (FLASHForward). The L-band superconducting technology allows accelerating fields of up to 0.8 ms in length at a repetition rate of 10 Hz (burst mode). A fast kicker-septum system picks one part of the 1 MHz electron bunch train and kicks it to the second beamline such that two beamlines are operated simultaneously with the full repetition rate of 10 Hz. The photoinjector operates three laser systems. They have different pulse durations and transverse shapes and are chosen to serve best for the given user experiment in terms of electron bunch charge, bunch compression, and bunch pattern. It is also possible to operate the laser systems on the same beamline to provide specific double pulses for certain type of experiments.

WEP049 **RF Power Waveguide Distribution for the RF Gun of the European XFEL at DESY**

B. Yildirim*, S. Choroba, V.V. Katalev, P. Morozov, Y. Nachtigal (DESY) E.M. Apostolov (Technical University of Sofia)*

The first section of the European XFEL provides the 43 m long injector. The injector consists of a 1.3 GHz RF gun, a 1.3 GHz cryomodule, a 3.9 GHz cryomodule and an extensive diagnostic section. The RF gun operates with a maximum RF peak power up to 6.5 MW, 10 Hz repetition rate and up to 650 µs pulse length. The starting point in the 1.5 cell normal conducting L-Band cavity of the RF gun is a Cs2Te photocathode, which produces electron bunches, which are injected into the superconducting accelerating section of the European XFEL. The RF power is generated by a 10 MW multi beam klystron and distributed to the RF gun through a RF power waveguide distribution system. In order to enhance the reliability of the distribution system, the peak power is minimized in every section of the system by splitting the power in different branches. The RF power reaches its maximum just in front of the RF gun after combination of all branches. An additional air pressure system decreases the break down level in the waveguides of the distribution. We present the layout of the waveguide distribution system for the XFEL RF gun at DESY and report on first operation experience.

`WEP050` **Temporal-Spatial Laser Pulse Shaping for Photo Cathode Lasers**

***C. Koschitzki**, Y. Chen, J.D. Good, M. Groß, P.W. Huang, I.I. Isaev, M. Krasilnikov, S. Lal, X. Li, O. Lishilin, G. Loisch, R. Niemczyk, H.J. Qian, H. Shaker, F. Stephan, G. Vashchenko (DESY Zeuthen) E. Khazanov, S. Mironov (IAP/RAS) T. Lang, L. Winkelmann (DESY)*

The beam emittance at FEL facilities like European XFEL and FLASH is dominated by the emittance sources in the electron injector. Shaping of the laser pulses that are employed to release electrons from the cathode of a photo injector, was shown in theory to allow improved beam emittance starting from the electron emission process. At the photo injector test facility at DESY in Zeuthen (PITZ) a laser system capable of controlling the temporal and spatial profile of laser pulses is being set up to demonstrate the predicted emittance reduction experimentally. The presentation will show its current capabilities to provide temporally and spatially shaped laser pulses from a pulse shaper operating at infrared (IR) wavelengths. Furthermore, results from a shape preserving conversion into fourth harmonic ultra-violet (UV), as needed for the photo emission process, will be presented.

`WEP051` **Pitz Experimental Optimization for the Aimed Cathode Gradient of a Superconducting CW RF Gun**

***M. Krasilnikov**, P. Boonpornprasert, Y. Chen, G.Z. Georgiev, J.D. Good, M. Groß, P.W. Huang, I.I. Isaev, C. Koschitzki, S. Lal, X. Li, O. Lishilin, G. Loisch, D. Melkumyan, R. Niemczyk, A. Oppelt, H.J. Qian, H. Shaker, G. Shu, F. Stephan, G. Vashchenko (DESY Zeuthen) M. Dohlus (DESY)*

A continuous wave (CW) mode operation of the European X-ray Free-Electron Laser (XFEL) is under considerations for a future upgrade. Therefore, a superconducting radio frequency (SCRF) CW gun is under experimental development at DESY in Hamburg. Beam dynamics simulations for this setup have been done assuming 100 pC bunch charge and a maximum electric field at the photocathode of 40 MV/m. Experimental studies for these parameters using a normal conducting RF photogun have been performed at the Photo Injector Test facility at DESY in Zeuthen (PITZ). The beam transverse emittance was minimized by optimizing the main photo injector parameters in order to demonstrate the feasibility of generating electron beams with a beam quality required for successful CW operation of the European XFEL for conditions similar to the SCRF gun setup.

`WEP052` **Simulations on Space Charge Dominated Emission at PITZ**

***X. Li** (DESY Zeuthen)*

In this paper we report our modeling and simulation on the space charge dominated emission in the L-band photocathode RF gun at the Photo Injector Test facility at DESY in Zeuthen (PITZ). It has been found that the emission curve, which shows the dependence of the extracted bunch charge out of the gun on the laser energy, doesn't agree very well with Astra simulations when the emission is near saturation or fully saturated. Previous studies with a core-halo model and an improved emission model have resulted in better agreement between experimental data and simulation, but discrepancies still exist. The space charge model for emission in Astra is a 2D model and can only fit axially symmetric beam, which is not the case for our laser beam. Therefore, a 3D FFT space charge solver including mirror charge effects has been developed to better model the transverse inhomogeneity in the laser beam. In this paper, comparisons with experimental data and Astra simulations will be reported.

`WEP053` **Development of a Multialkali Antimonide Photocathode at INFN LASA**

***S.K. Mohanty** (DESY Zeuthen) G. Guerini Rocco, C. Pagani (Università degli Studi di Milano & INFN) P. Michelato, L. Monaco, D. Sertore (INFN/LASA)*

Owing to their excellent properties including high quantum efficiency (QE), low emittance, good lifetime and fast response, alkali antimonides photocathodes has been considered as one of the eminent candidates for the electron source of energy recovery linacs (ERL) and free electron lasers (FEL). Nevertheless, their sensitivity to vacuum condition requires specific R&D before they can operate in a RF Gun. For this reason, we have started to develop specifically K-Cs-Sb based multialkali photocathodes at INFN LASA. The primary goal is to develop a stable and reproducible alkali antimonide films on INFN plugs and test them in the photoinjector test facility PITZ at DESY Zeuthen. In this report, we present and discuss about the results so far obtained on KCsSb material and the status of the new preparation system specifically designed for these sensitive materials.

`WEP054` **Beam Dynamics Optimization of a Normal-Conducting Gun Based CW Injector for the European XFEL**

***H. Shaker**, S. Lal, H.J. Qian, G. Shu, F. Stephan (DESY Zeuthen)*

The European XFEL is operating up to 17.5 GeV electron energy with maximum 0.65% duty cycle. There is a prospect for the continuous wave and long pulse mode (CW/LP) operation of the European XFEL, which enables more flexible bunch pattern time structure for experiments, higher average brightness and better stability. Due to engineering limitations, the maximum electron beam energy in the CW/LP mode is about $8/10^{-14}$ GeV, which puts more pressure on the injector beam quality for lasing at the shortest wavelength. This paper optimizes the beam dynamics of an injector based on a normal-conductiong VHF gun. The results of various bunch charges from 20 to 300pC are presented.

WEP055 Multiphysics Analysis of a CW VHF Gun for European XFEL

***G. Shu**, Y. Chen, S. Lal, H.J. Qian, H. Shaker, F. Stephan (DESY Zeuthen)*

R&D for a possible future CW mode operation of European XFEL started after the successful commissioning of the pulse mode operation. For the CW electron source upgrade, a fully superconducting CW gun is under experimental development at DESY in Hamburg, and a normal conducting (NC) CW gun is under physics design at the Photo Injector Test facility at DESY in Zeuthen (PITZ) as a backup option. Based on the experience of the LBNL on a 187 MHz gun, the DESY 217 MHz gun increased the cathode gradient and RF power to 28 MV/m and 100 kW, respectively, to further improve the beam brightness. In this paper, the multiphysics analysis investigating the RF, thermal and mechanical properties of the 217 MHz NC CW gun are presented.

WEP056 Engineering Design of Low-Emittance DC-SRF Photocathode Injector

***Y.Q. Liu**, M. Chen, W. Cheng, S. Huang, L. Lin, K.X. Liu, S.W. Quan, F. Wang (PKU)*

The second-generation DC-SRF (DC-SRF-II) photocathode injector is under development at Peking University. The goal is to achieve an emittance below 0.5 mm-mrad at the bunch charge of 100 pC and repetition rate of 1 MHz. The engineering design of the DC-SRF-II photoinjector was accomplished this May and the fabrication is ongoing now. This paper will present our recent work, and especially, we will focus on the details of engineering design.

WEP057 Performance Optimization of Low-Emittance DC-SRF Injector Using Cs2Te Photocathode

***S. Zhao** (Peking University) S. Huang, K.X. Liu, Y.Q. Liu, D.M. Ouyang (PKU)*

A low-emittance DC-SRF injector (DC-SRF-II) is under construction at Peking University, in the earlier design of which K2CsSb photocathode was chosen. Recently we changed the cathode to Cs2Te, which is more widely used nowadays, and carried out a detailed performance optimization. In this paper, we present our latest simulation results, which show that an emittance under 0.5 mm-mrad can be achieved at the bunch charge of 100 pC.

WEP058 Drive Laser Temporal Shaping Techniques for Shanghai Soft X-ray Free Electron Laser

***X.T. Wang**, T. Lan, B. Liu, M. Zhang, W.Y. Zhang (SINAP) , C.L. Li (Shanghai Advanced Research Institute) B. Liu (SARI-CAS)*

The design of Shanghai soft X-ray free electron laser (SXFEL) is based on laser driven photocathode, which can provide emittance <2.0 mm·mrad with 500 pC charge. The temporal shape of drive laser has significant influence on the electron beam emittance and brightness. This paper gives an overview of various temporal shaping methods for shaping the drive laser temporal structure, and then present the temporal shaping techniques for SXFEL. For measuring the laser temporal structure, such as pulse length and rising time, online auto-correlation and cross correlation diagnostic system are developed. Experiment results are also presented to show the relation between the laser temporal structure and electron beam emittance.

WEP059 Characterizing a Coherent Electron Source Extracted From a Cold Atom Trap

***H. Luo** (SWUST)*

In order to generate a fully coherent free electron laser (FEL) within a compact system, one approach is to interact a coherent electron bunch with a high power laser operating in the quantum FEL regime. The coherent electron source is obtained by ionizing the Rydberg atoms in a magneto-optical trap (MOT). The qualities of the electron source will have direct effects on the brightness, coherence, and line width of the free electron laser. A high quality ultra-cold electron source is obtained by carefully optimizing the extraction electrode structure, the acceleration and focusing system as well as the MOT. Through parameter optimization, a coherent electron source with a temperature lower than 10 K is obtained. Details of the optimization and the characteristics of the coherent electron source are reported in this paper.

WEP060 Study on a Coherent Electron Source Extracted From a Cold Atom Trap

***Y.X. Xu**, J. Guo (SWUST)*

To generate a fully coherent free electron laser (FEL) within a compact system, one approach is to interact a coherent electron bunch with a high power laser operating in the quantum FEL regime. The coherent electron source is produced by ionizing the Rydberg atoms in a magneto-optical trap (MOT). Such electron pulses are then accelerated and further manipulated outside of the MOT for frontier scientific research. The quality of the electron source will have direct impacts on the scientific application as well as the brightness, coherence, and line width of the FEL pulse. To study these, a particle-in-cell (PIC) code is adopted to simulate the electron bunch dynamics. Optimization details and the coherent electron source characteristics are presented in this paper.

WEP061 Diagnose the Quality of a Coherent Electron Source Extracted From a Cold Atom Trap With Kapitza-Dirac Effect

***J.H. Zhou** (Southwest University of Science and Technology)*

To generate a fully coherent free electron laser (FEL) within a compact system, one approach is to interact a coherent electron bunch with a high power laser operating in the quantum FEL regime. The coherent electron source is obtained by ionizing the Rydberg atoms in a magneto-optical trap (MOT). The quality of the electron source will have direct impacts on the brightness, coherence, and line width of the FEL. To quantify the coherence of the so obtained electron source, we develop an approach utilizing the Kapitza-Dirac effect. Theoretical framework and calculation are presented in this paper. Experimental schemes based on these theoretical predictions are also reported.

WEP062 **Test of Cs2Te Thickness on Cathode Performance at PITZ**

***P.W. Huang** (TUB) Y. Chen, M. Groß, I.I. Isaev, C. Koschitzki, M. Krasilnikov, S. Lal, X. Li, O. Lishilin, D. Melkumyan, R. Niemczyk, A. Oppelt, H.J. Qian, H. Shaker, G. Shu, F. Stephan, G. Vashchenko (DESY Zeuthen) S. Lederer (DESY) P. Michelato, L. Monaco, D. Sertore (INFN/LASA)*

Cesium telluride is a widely used cathode in photo injectors, and its performance is one of the keys for not only emittance but also reliable operation. Over the years lots of experiences with Cs2Te photocathodes produced with the same recipe and thickness were gained at the DESY photo injectors, but cathode performance dependence on the cathode layer thickness were not investigated. In this paper, we test fresh Cs2Te cathodes with different thickness at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The QE and thermal emittance of these cathodes inside the high gradient RF gun will be compared. Besides, the injector emittance under the operation conditions of the XFEL will also be measured with these cathodes.

WEP063 **The Preliminary Study of a Pre-Bunched Terahertz Free Electron Laser by a Velocity Bunching Scheme**

***R. Huang**, Q.K. Jia, H.T. Li, Z. Zhao (USTC/NSRL)*

Terahertz (THz) radiation has broad applications in biological sciences, materials imaging and radar communications and so on. High-power, frequency-adjustable THz radiation sources are desired. An electron beam, generated in a photoinjector and bunched at terahertz (THz) frequency, will excite a coherent THz radiation when entering an undulator. The radiation power mainly depends on the particle number and the bunching factor of the electron beam, which is limited by the space charge effect among the microbunches and the total rf phase width the macrobunch occupied. Previously we have designed a pre-bunched THz free electron laser (FEL) with the radiation frequency covering 0.5-5 THz. While the radiation intensity for the lower frequency (below 1~THz) is not very high because of the large energy spread and the low bunching factor. We will report a THz FEL by a velocity bunching scheme, which could realize more highly bunched beam especially in the low THz frequency region. The physical design of the electron source is described in detail.

WEP064 **Performance of S-Band Photocathode RF-Gun With Coaxial Coupler**

***J.H. Hong**, J.H. Han, C.-K. Min (PAL)*

To improve the characteristics of electron beams, a new s-band photocathode RF gun with a coaxial coupler has been developed and fabricated at the Pohang Accelerator Laboratory (PAL). This new RF gun improves the field symmetry inside a cavity cell by applying the coaxial coupler, and the cooling performance by improving the cooling lines. The RF gun is installed in the injector test facility (ITF) for high power RF tests. This paper reports the recent results on the RF conditioning process and the beam tests of the RF gun with high power RF at ITF. We present and discuss the measurement results of the basic beam parameters.

WEP065 **Recent Beam Quality Improvements in the MAX IV Photoinjector**

***J. Andersson**, M. Kotur, F. Lindau, E. Mansten, S. Thorin (MAX IV Laboratory, Lund University)*

The beam quality from the photocathode pre-injector at the MAX IV linac is of importance for the current SPF, but also for the future MAX IV SXL. Several experiments were made during the last years to improve the beam quality, in combination with development of suitable diagnostics. In this paper we report on the results, and show a measured emittance of 0.7 mm mrad for 100 pC. We also connect the results to recent experiments in the gun test facility at MAX IV. Finally further improvements currently planned will be reported on, with a target emittance of below 0.3 mm mrad.

WEP066 **Progress on Normal Conducting CW APEX2 Electron Gun Design**

***D. Li**, H.Q. Feng, D. Filippetto, M.J. Johnson, A.R. Lambert, T.H. Luo, J. Qiang, F. Sannibale, J.W. Staples, S.P. Virostek, R.P. Wells (LBNL) H.Q. Feng (TUB)*

Recent progress on the design of a normal conducting CW electron gun, APEX2 (Advanced Photo-injector Experiment 2) at LBNL is reported. APEX2 is an upgrade of the successful APEX gun at LBNL and the LCLS-II injector at SLAC, aiming at providing higher beam brightness and higher energy for applications for FELs such as LCLS-II High Energy upgrade, UED and UEM. For APEX2, we have adopted a two-cell cavity design at 162.5 MHz, with both cell profiles optimized using MOGA techniques developed at LBNL. The proposed APEX2 gun design has a 30+ MV/m gradient at the cathode and an output energy of 1.5 MeV or above. Beam dynamics studies show that with the APEX-like injector layout, a transverse emittance of 0.1 μm at 100 pC can be achieved. Detailed RF designs and beam dynamics studies are presented. The APEX2 engineering design retains the techniques that has been successfully demonstrated in the APEX operation in RF and vacuum. In addition to vacuum ports, two RF power couplers are placed on the equator of each cell while keeping RF tuning at end-walls. FEA analysis and vacuum calculations have been conducted to validate and support these design improvements.

WEP067 **Development and Commissioning of a Flip Coil System for Measuring Field Integrals**

***J.E. Baader** (UNICAMP)*

Many techniques for measuring magnetic fields are available for accelerator magnets. In general, methods based upon moving wires are suitable for characterizing field harmonics, and first and second field integrals. The flip coil moving wire technique stands out due to simplicity, speed, precision, and accuracy. We aimed to develop a reliable, fast and precise flip coil system capable of characterizing field integrals in the two transverse axes. The coil was a single turn loop made of insulated beryllium copper wire. The width of the loop was 5 mm. The approach of measuring second field integrals by changing the coil's width at one of the ends was analyzed and included in the system. High-performance motorized stages performed angular and transverse positioning of the coil, while manual stages were used to stretch the wire, execute fine adjustments in its transverse position, and change coil's geometry. Initial tests with the Earth's field and also with a reference magnet of 126 Gauss-centimeter (G.cm) demonstrated that the system achieves repeatability of 0.2 G.cm for a 60-cm long coil. This work was carried out for the LCLS-II project at SLAC.

WEP068 Development of Cryogenic Undulators at SOLEIL

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Cryogenic Permanent Magnet Undulators (CMPU) can provide high brightness radiation at short wavelengths, by taking advantage of the permanent magnet enhanced performance at low temperature. Three 2 m long CPMUs of period 18 mm (U18) have been built at Synchrotron SOLEIL: two of them are used on the Anatomix and Nanoscopium beamlines, the third one is used in the cryo-ready configuration for the COXINEL laser plasma based Free Electron Laser test experiment. A 3 m long cryo-ready CPMU of period 15 mm is under construction at SOLEIL for an operation down to 3 mm gap, both for FEL and storage ring (third generation and diffraction limited light sources) based applications. Construction, optimization, magnetic measurements with specific embedded measurement bench are presented. The quality of the undulators is validated by measured undulator radiation, either on the long Synchrotron SOLEIL beamlines at 2.75 GeV or on the COXINEL test experiment at 160 MeV.

WEP069 Single-Shot Temporal Characterization of XUV Pulses at FLASH by THz Streaking

***I.J. Bermudez Macias**, S. Düsterer, R. Ivanov (DESY) J. Liu (EuXFEL)*

Results of single-shot temporal characterization of XUV SASE FEL pulses generated by FLASH and measured with a THz- field-driven streaking experiment are presented. In order to investigate the limits of the technique, measurements at different pulse durations from sub 10 fs to 350 fs and different XUV wavelengths have been recorded. Limits and possible error sources of the diagnostic method are discussed. Furthermore, the measurements allow a detailed investigation of the interplay between different properties of the strongly fluctuating self-amplified spontaneous emission (SASE) radiation. Correlations between pulse duration, pulse energy, spectral distribution, arrival time, electron bunch shapes,... are explored in the experimental data as well as in simulations. In addition, the results of different pulse reconstruction methods to retrieve the actual XUV pulse shape have been compared to verify that our method is the most optimal. A permanent THz streaking setup for pulse diagnostics has been installed at the FLASH2 hall (Beamline FL21) and recently commissioned. Results of the first experiments will be presented showing the reliability and accuracy of the diagnostic method.

WEP070 Influence of Radiation Exposure on the FEL Performance at FLASH

***B. Faatz**, M. Tischer, P. Vagin (DESY)*

FLASH has been operated as user facility for about 14 years. In this time, the total charge accelerated and transported through the FLASH1 undulator is around 35 Coulomb. Based on detailed monitoring of the radiation loss and reference measurements on degradation of the magnetic field of the undulator, we have performed simulations to study the change in FEL performance and first comparison of the simulations with the changes we observe during operation.

WEP071 Flexible High Power and Repetition Rate OPCPA Pump-Probe Laser System for the FLASH2 XUV FEL Beamline at DESY

***T. Lang**, S. Alisauskas, U. Grosse-Wortmann, I. Hartl, T. Huelsenbusch, B. Manschwetus, C. Mohr, J.M. Müller, F. Peters, S. Schulz, A. Swiderski, J. Zheng (DESY)*

FLASH is currently the worldwide only high repetition-rate XUV and soft X-ray free-electron laser (FEL) facility. It consists of two simultaneously operating FEL beamlines. We report on the addition of a highly flexible, high repetition-rate femtosecond-laser system for pump-probe experiments at the FLASH2 FEL beamline. The laser system is based on optical parametric chirped pulse amplification (OPCPA) technology, the only method capable of producing the required wavelength and pulse duration tunability with sufficient pulse energy. The laser system delivers long-term stable output pulses and a temporal structure matching the 10 Hz - 800 µs bursts-mode of FLASH. The laser is designed to allow for a fast change of the pulse repetition rates between 50 kHz and 1 MHz. The first laser operation point (100 kHz, 400 µJ) is commissioned for user experiments, where laser pulses with tunable transform limited pulse duration between < 15 fs and 100 fs are transported to two instruments via a >40 m long relay-imaging beamline. Each instrument features a modular optical delivery station for pulse diagnostics, compression, attenuation, frequency conversion and focusing to the interaction chamber.

WEP072 Expected Radiation Properties of the Harmonic Afterburner at FLASH2

***M. Mehrjoo**, B. Faatz, G. Paraskaki, M. Tischer, P. Vagin (DESY)*

We discuss the afterburner option to upgrade the FLASH2 undulator line, at the FLASH facility in the Hamburg area, for delivering short wavelengths down to approximately 1.5 nm with variable polarization. This relatively straightforward upgrade enables us the study of the scientific cases in L- absorption edges of rare earth metals. The proposed afterburner setting with an energy upgrade to 1.35 GeV would potentially cover many of the community's requests for the short wavelengths radiation and circular polarization. We also study the influence of reverse tapering on the radiation output. This contribution presents a series of simulations for the afterburner scheme and some of the technical choices made for implementation.

WEP073 Experience With MCP-Based Photon Detector at FLASH2

***O.I. Brovko**, A.Yu. Grebentsov, E. Syresin (JINR) S. Grunewald, E. Mueller, E. Schneidmiller, K.I. Tiedtke, M.V. Yurkov (DESY)*

In this report we describe MCP-based radiation detector at FLASH2. Micro-channel plate (MCP) detects scattered radiation from a target (mesh). Use of different targets and geometrical positioning of the MCP plates provides control of photon flux on the detector. MCP detector covers the whole wavelength range of FLASH2 (from 2.x nm to 100 nm). Dynamic range spans from sub-nJ to mJ level (from spontaneous to saturation level).

Relative accuracy of single-shot radiation pulse energy measurements in the exponential gain regime is about 1%. DAQ based software is under development which allows to perform cross-correlation of the SASE FEL performance with electron beam jitters. As a result, it is possible: (i) to organize efficient feedback for cancellation of machine jitters, and (ii) to use statistical techniques for characterization of SASE FEL radiation deriving such important quantities as gain curve (gain of the radiation pulse energy and its fluctuations along the undulator), radiation pulse duration, coherence time, and degree of transverse coherence. Relevant experimental results are presented in the paper.

WEP074 **The HIgh Resolution Hard X-Ray Single Shot Spectrometer (HIREX Spectrometer) Installation and Commissioning in SASE2 Beamline of the European XFEL**

***N.G. Kujala**, W. Freund, J. Grünert, A. Koch, J. Laksman, J. Liu, M.P. Planas (EuXFEL)*

The European X-ray Free Electron Laser (XFEL) facility in Germany will deliver pulses at 4.5 MHz repetition rate with femtosecond pulse length. There are three undulators: SASE1 and SASE2 provide hard X-ray FEL radiation, while SASE3 provides soft X-ray radiation. An important task of the X-ray photon diagnostics group is to provide reliable tools and feedback systems for measurements aiming at studying the properties of the FEL radiation which is created by the SASE process (Self Amplified Spontaneous Emission), whose stochastic nature gives rise to shot-to-shot fluctuations in most beam properties and resulting spectrum will vary considerably from shot to shot. In order to cover these variations, the HIREX spectrometer has been installed in the photon tunnel XTD6 of the SASE2 undulator branch as feedback system for machine optimization. HIREX spectrometer is an on-line device, based on bent silicon and diamond crystals as a dispersive element, and a MHz-repetition rate Gotthard detector. In this contribution we will discuss the installation and commissioning of HIREX spectrometer and will present the preliminary spectral measurement.

WEP075 **A Photoelectron Spectrometer for Soft X-Ray Photon Diagnostics at European XFEL**

***J. Laksman**, J. Buck, F. Dietrich, J. Grünert, M. Ilchen, J. Liu, M.P. Planas (EuXFEL) L. Glaser, Th. Maltezopoulos, J. Viefhaus (DESY)*

The constructions of X-ray Free-Electron Laser (XFEL) facilities with high intensity, high repetition rate and short pulse length have created a need for photon diagnostics that is capable of handling these conditions without damage or being overloaded, but at the same time provide relevant beam parameters to the users. A non-invasive principle for photon diagnostics is the usage of low density matter where gas targets are ionized by XFEL pulses and the resulting ions or electrons are detected. We present a Photo-Electron Spectrometer (PES) for on-line and pulse-resolved diagnostics of the spectral distribution and polarization at the Soft X-ray SASE3 beamline at the European XFEL facility in Schenefeld, Germany. The PES device consists of sixteen electron Time-Of-Flight spectrometers oriented perpendicular to the incoming X-ray beam in order to monitor the polar angle of the electromagnetic field. A target gas is injected as an effusive jet in the interaction region via a capillary. For every pulse we detect the photoelectrons Time-Of-Flight and polar angular distribution from which we can calculate photon-energy with 1eV resolution and polarization with two degree accuracy.

WEP076 **A Superconducting Undulator With Variable Polarization Direction for the European XFEL**

***Y. Li** (EuXFEL) R. Rossmanith (DESY)*

In the SASE3 beam line at the European XFEL a planar undulator produces linearly polarized radiation. In order to obtain a circularly polarized radiation an afterburner will be installed to produce coherent radiation with variable polarization. Recently Argonne National Lab developed a super conductive undulator (called SCAPE) for a storage ring which allows to change polarization direction and field strength without moving mechanically the undulator parts. In this paper it is investigated if a similar device could be useful for an FEL. Such device is also a possible choice for the future undulator beam lines where circular and variable polarization are required.

WEP077 **Design and Commissioning of a Photon Arrival Time Monitor at the European XFEL**

***J. Liu**, J. Grünert, H. Kirkwood, R. Letrun, A. Mancuso (EuXFEL) T. Sato (CFEL)*

The European X-ray Free Electron Laser (EuXFEL) has been in operation since 2017 and is enabling novel research of extremely small structures on the nano to micrometer length scale and probing ultrafast phenomena and dynamics in the femtosecond to millisecond time range. Exploiting the unprecedented high FEL peak brilliance, X-ray induced dynamics can be observed by applying X-ray pump - optical probe schemes that open a new era in physics and chemistry. Typically, the timing of pulses from two independent sources can only be controlled down to the level of naturally occurring timing jitter, which turns out to be a major limiting factor for such experiments. This inevitably calls for a photon diagnostics tool to precisely determine the relative arrival time for sorting and tagging the experimental data. In this report, we describe the design and first commissioning of the Photon Arrival Monitor (PAM) at the SPB/SFX instrument at the European XFEL. This first measurement of timing jitter from the level of single pulses per train at 10 Hz up to MHz repetition rates represents an important step towards realizing ultrafast experiments at the European XFEL.

WEP078 **Pulse Energy Measurements and Position Monitoring at European XFEL using X-ray Gas Monitors**

***Th. Maltezopoulos**, F. Dietrich, W. Freund, J. Grünert, A. Koch, J. Laksman, J. Liu, M.P. Planas (EuXFEL) U. Jastrow, A.A. Sorokin, K.I. Tiedtke (DESY) A.A. Sorokin (IOFFE)*

X-ray Gas Monitors (XGMs) are operated at European XFEL for non-invasive single-shot pulse energy measurements and average beam position monitoring. They are used for machine SASE tuning and operation and for sorting and normalizing single-shot experimental data according to the pulse energy. The XGMs were developed at DESY based on the specific requirements for the European XFEL. Six units are meanwhile in continuous operation. In our contribution we will present the XGM setup, the locations in the European XFEL tunnels, and data from the SASE1, SASE2, and SASE3 beamlines. We present pulse energy measurements with an absolute measurement uncertainty of 7-10 percent, single-shot correlations between different XGMs, and between XGMs and other pulse resolved measurement devices. Additionally, we show simultaneous position measurements close to the undulator and at the end of the tunnel and the correlation between beam position data acquired by an XGM and an imager.

WEP079 **Effect of Heat Load on Cryo-Cooled Monochromator at High-Repetition Rate Hard X-Ray FEL: Simulations and First Experimental Observations**

__I. Petrov__, M. Dommach, W. Lu, A. Madsen, L. Samoylova, R. Shayduk, H. Sinn, V. Sleziona, A. Zozulya (EuXFEL) X. Dong (European X-Ray Free-Electron Laser Facility GmbH) D. Shu (ANL)

European XFEL (EuXFEL) generates high-intensity ultra-short pulses at MHz repetition rate. At hard X-ray instruments, cryo-cooled silicon monochromators are used to reduce pulse bandwidth. Here, first experimental observations during commissioning of a cryo-cooled monochromator at Materials Imaging and Dynamics (MID) instrument are presented and compared with heat flow simulations. A thermal relaxation time is estimated and compared with arrival time interval between pulses. This provides the repetition rate tolerable for stable operation of monochromator.

WEP080 **ROSA: Reconstruction of Spectrogram Autocorrelation for Self-Amplified Spontaneous Emission Free-Electron Lasers**

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Diagnostics of XFEL emission properties, in particular pulse duration, spectrum and temporal profile is very important for analysis of the experimental results. In this work we propose a cost-effective method to examine these properties of SASE pulses. It only requires an ensemble of measured SASE spectra and provides the temporal autocorrelation of the ensemble-averaged Wigner distribution of SASE FEL pulses.

WEP081 **Design and Development of High-Speed Data Acquisition System and Online Data Processing with a Heterogeneous FPGA/GPU Architecture**

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The superradiant THz sources at TELBE facility is based on the new class of accelerator driven terahertz (THz) radiation sources that provide high repetition rates up to 13 MHz, and flexibility of tuning the THz pulse form. The THz pulses are used for the excitation of materials of interest, about two orders of magnitude higher than state-of-the-art tabletop sources. Time-resolved experiments can be performed with a time resolution down to 30 fs using the novel pulse-resolved Data Acquisition (DAQ) system. However, the increasing demands in improving the flexibility, data throughput, and speed of the DAQ systems motivate the integration of reconfigurable processing units close to the new detectors to accelerate the processing of tens of GBytes of data per second. In this paper, we introduce our online ultrafast DAQ system that uses a GPU platform for real-time image processing, and a custom high-performance FPGA board for interfacing the image sensors and provide a continuous data transfer.

WEP082 **Superconducting Undulator Coils With Period Length Doubling for XFEL Applications**

__S. Casalbuoni__, N. Glamann, A.W. Grau, T. Holubek, D. Saez de Jauregui (KIT)

Only since few years it has been demonstrated experimentally that NbTi based superconducting undulators (SCUs) have a higher peak field on axis for the same gap and period length in operation with electron beam with respect to permanent magnet undulators. Moreover, SCU technology allows switching of the period length by changing the current direction in one of separately powered subset of winding packages of the superconducting coils. This feature further broadens the energy range of the emitted photons. A SASE line of such undulators with period doubling in the range between 15-20 mm to 30-40 mm could be of great advantage for example for the European XFEL. It would allow to cover a photon energy range between few keV to about 100 keV for an electron beam energy of 17.5 GeV, and to cover up to 25 keV, as presently done with the existing SASE lines, in case of continuous wave (CW) operation mode at 7.8 GeV. As a first step, a 0.41 m long superconducting undulator coil with switchable period length between 17 mm and 34 mm has been developed. In this contribution we describe the design and report on the quench tests, as well as on the magnetic field measurements.

WEP084 **A Cryogenic Undulator for a Laser-Plasma Driven FEL Experiment**

__M. Trunk__ (University of Hamburg, Institut für Experimentalphysik) J. Bahrdt, B. Schulz (HZB) A.R. Maier (University of Hamburg)

Laser-plasma accelerators are promising candidates to drive a next generation of compact FELs. The LUX plasma accelerator, developed and operated in a collaboration of Hamburg University and DESY, recently demonstrated the generation of spontaneous undulator radiation from a laser-plasma electron beam. A future upgrade of the beamline, currently under commissioning, will include the cryogenic FEL-ready undulator FROSTY to demonstrate first FEL gain from laser-plasma electron beams following the decomression scheme. By pushing the tolerances of the mechanical components to its limits, developing new magnetic alloys which unfold their full potential within cryogenic temperatures, and fulfilling the requirements of the high vacuum standard specified at DESY, we are currently commissioning an undulator with 15 mm period length and a peak field of 2.2 T. Our calculations show, that this undulator will support the demonstration of FEL gain from a plasma-accelerator using electron beams available in the lab already today. Here, we will present the design, manufacturing and the current commissioning status of the FEL undulator.

WEP085 **Field Integral Measurements of 20 mm Period Hybrid Undulator and Future Measurement Plan**

__M. Gehlot__, S.M. Khan, R. Khullar, G. Mishra (Devi Ahilya University) J. Hussain (Department of Applied Physics, UIT) F. Trillaud (UNAM)

The Insertion device development and Application (IddA) laboratory of Devi Ahilya University, Indore, India has ongoing activities on undulator design and development. In this paper, we analyze the field and phase integral properties of the IddA U20 undulator. The IddA U20 is a prototype NdFeB-cobalt steel hybrid in house designed device of 20 mm period length with twenty five periods. The uniform gap variable hybrid undulator provides magnetic flux density (in rms) from 2400 G to 500 G in the 10 mm - 20 mm gap range. The theory of undulator field integral and phase integral equations are reviewed and the results are analyzed on the basis of tolerance formulas and Hall Probe measurements. The electron trajectory of the IddA U20 undulator lacks straightness. The analytical basis has been used effectively by local manipulation of the field strengths of the magnets to improve straightness in the trajectory. The phase error is improved through improved straightness in the trajectory. A short description of the measurement plan of the undulator on the pulsed wire bench is described.

WEP086 **Capabilities of Terahertz Super-Radiance from Short Electron Bunches Moving in Micro-Undulators**

***N. Balal**, V.L. Bratman, A. Friedman, Yu. Lurie (Ariel University) V.L. Bratman (IAP/RAS)*

An available frequency range of coherent radiation from ps bunches with high charge and moderate particle energy significantly enhances if one uses a micro-undulator with a high transverse field. Such an undulator can be implemented by redistributing a strong uniform magnetic field by a helical ferromagnetic or copper insertion. According to simulations and experiments with prototypes, a steel helix with a period of (8-10) mm and an inner diameter of (1.5-2) mm inserted in the 3T-field of solenoid can provide an undulator field with an amplitude of 0.6 T. Using a hybrid system with a permanently magnetized structure can increase this value up to 1.1 T. The necessary steel helices can be manufactured on the machine, assembled from steel wires, formed from powder, or 3D - printed. Simulations based on the WB3D code demonstrate that using such undulators with the length of (30-40) cm enable single-mode super-radiance from bunches with energy of 6 MeV, charge of 1 nC and duration of 2 ps moving in an over-sized waveguide in frequency range of 3-5 THz. The calculated efficiency of such process is (2-4)% that many times exceeds efficiency for short bunches of the same initial density.

WEP087 **High Magnetic Field Pure Permanent Magnet Undulator**

***L.J. Chen** (CAEP/IAE)*

A modified pole structure of pure permanent magnet (PPM) undulator is proposed to enhance the peak magnetic field. The poles are segmented into two blocks with the magnetization directions tilted, and the peak magnetic field is obviously higher than that of conventional PPM undulators. The methods have been proposed to solve the issue of the narrowed good field region caused by the new structure. The harmonic properties of the magnetic field have also been discussed.

WEP088 **Towards Extremely High Resolution Broad-Band Flat-Field X-Ray Spectrometer**

***B. Li** (SINAP)*

The paper will report a new design of grazing incidence X-ray spectrometer, optimized to achieve very high spectral resolution throughout the designated spectral range, casting an excellent flat field for meridionally diffractive beam, while confining its sagittal astigmatism to enhance the spectral intensity. In 'water window' (i.e. wavelength range of 2-5 nm), the resolving power of 20,000-40,000 was demonstrated for slit-less meridional source size of 50 µm (rms), and for upgraded version implementing a pre-convex mirror (analogously to Wolter-III structure), the resolving power increases to 100,000-200,000. When the design algorithm is applied to higher photon-energies, e.g. above 1 keV, it could deliver a resolving power of >50,000, representing a promising spectral diagnostics for free electron laser (FEL) in soft X-ray range. This extreme resolving power could well resolve single spikes in the self-amplified spontaneous emission (SASE) spectrum and reflect the critical SASE pulse length.

WEP089 **Pulse Energy Measurement at the SXFEL**

***Z.P. Liu** (SINAP)*

The test facility is going to generate 8.8 nm FEL radiation using an 840 MeV electron linac passing through the two-stage cascaded HGHG-HGHG or EEHG-HGHG (high-gain harmonic generation, echo-enabled harmonic generation) scheme. Several methods have been developed to measure the power of pulse. The responsivity of silicon photodiode having no loss in the entrance window. Silicon photodiode reach saturates at the SXFEL. In this work, we simulated the attenuator transmittance for different thicknesses. We also show the preparations of the experiment results at the SXFEL .

WEP090 **Design of an Off-Line Method to Simulate Single Particle Imaging for SHINE**

***Q. Xie** (ShanghaiTech University)*

SHINE facility will be the first hard X-ray free electron laser with 1 MHz of China. The entire facility is composed of three beamlines and ten endstations and will be accomplished in 2024. The single particle and molecular Coherent Diffractive imaging Endstation (CDS) is one of the primers in the first phase. In the early stage of CDS endstation construction, an off-line single particle diffractive imaging system based on a high-repetition femtosecond laser and an ultrafast camera are set up in the lab to simulate the XFEL single particle imaging (SPI) process. Lens and apertures are used to control the energy per pulse of the laser at the same level of XFEL. As an effective auxiliary method to develop imaging technology, the imaging system is focused on three crucial problems of SPI: first, processing for massive raw data of diffractive patterns with advanced algorithms. Second, rapid fix-target scanning method with the translation stage for rare samples. Moreover, the third is to develop a novel 3D imaging method based on diffractive principle with a single shot for different samples.

WEP091 **Conceptional Design of the IEM Instrument at SHINE for XPCS**

***Y. Xu** (ShanghaiTech University)*

Shanghai HIgh repetition rate XFEL aNd Extreme light facility (SHINE) is a 1 MHz rep-rate hard X-ray free electron laser facility. Currently there are 3 beamlines and 10 endstations under construction. The IEM instrument

(Imaging Endstation for Materials) at SHINE is a dedicated instrument for the study of materials using coherent imaging and scattering techniques like CDI, holography and XPCS. By measuring the temporal correlation between diffraction patterns, XPCS is able to reveal molecular and even atomic dynamics on the time scale of seconds to femotseconds. The SHINE facility offers highly brilliant and coherent continuous X-ray pulses with pulse length less than 100 fs, which are beneficial for both sequential and ultra-fast XPCS study. In order to enable XPCS measurements on various material systems like particle dispersion, metallic glass and polymer at different geometries, special technical considerations shall be carefully made in the design phase. Here we present the conceptional design of the IEM instrument for XPCS studies, focusing on key components like attenuators, monochromators, KB , CRL, split-delay line, sample chamber and detectors.

WEP092 **Spare Undulator Production for PAL-XFEL Hard X-Ray Beamline**

***J.H. Han**, Y.G. Jung, D.E. Kim, S.J. Lee (PAL)*

In the PAL-XFEL hard X-ray beamline, 20 undulator segments with a 26 mm period and a 5 m length are installed and operated for XFEL user service. One spare undulator was manufactured in December 2018. The magnetic measurements and tuning was carried out recently. We report the measurement and tuning results.

WEP093 **Radiation Damage Monitoring at PAL-XFEL**

***S.J. Lee**, J.H. Han, Y.G. Jung, D.E. Kim, G. Mun (PAL)*

Pohang Accelerator Laboratory X-ray Free Electron Laser (PAL-XFEL) has two undulator beamlines, one hard and one soft X-ray beamlines. These two undulator beamlines are in operation since 2017. To maintain the FEL radiation property, the B-field properties of PAL-XFEL undulators need to be kept at certain level. Under the 10 GeV beam operation condition, the accumulated radiation can affect the permanent magnet properties of the undulators. However, the radiation damage of permanent magnet can be different by the operation environment and the geometry of the undulator. Accumulated radiation sensors and a miniature undulator with a few periods are installed in the PAL-XFEL hard X-ray undulator line to monitor the undulator radiation damage. In this proceeding, the radiation monitoring activities and the recent measurement results will be introduced.

WEP094 **Variable-Period Variable-Pole Number Hybrid Undulator Design for Novosibirsk THz FEL**

***I.V. Davidyuk**, O.A. Shevchenko, V.G. Tcheskidov, N.A. Vinokurov (BINP SB RAS)*

The undulator developed for the first FEL of Novosibirsk FEL facility employs variable-period structure based on the hybrid undulator scheme with poles splinted into halves. The design was adapted to deliver optimal performance, estimations were made based on results of three-dimensional field simulations. According to the modeling results, the undulator will not only widen significantly the first FEL tuning range moving the long-wavelength border of the first harmonic from 200 µm to 450 µm but also provide wider aperture and increase efficiency at shorter wavelengths.

WEP095 **The Athos Soft X-Ray Beamlines at SwissFEL**

***R. Follath**, U. Flechsig, L. Patthey, U.H. Wagner (PSI)*

After the successful start of the hard X-ray FEL at SwissFEL in 2016, the soft X-ray FEL ATHOS at SwissFEL is expected to deliver the first beam by end of 2019. This contribution describes the beamlines attached to the FEL and reports on the status and plans for this soft X-ray facility. The ATHOS facility will operate three end stations. Two stations are already defined and are currently in the design and construction phase whereas the third station will be defined in the future. The first station (AMO) is dedicated to Atomic and Molecular physics as well as nonlinear spectroscopy. It is expected to get light in mid 2020. The second station (Furka) is for condensed matter physics. The beamline consists of a grating monochromator and distributes the beam downstream of the grating chamber by means of horizontal deflecting mirrors. Pink and monochromatic beam operation is foreseen at all branches. The monochromator uses variable line-spacing gratings on spherical substrates with a variable included angle and operates without an entrance slit. Its mechanics is based on the SX-700 design, but with the grating facing up and the mirror facing down. The installation of the beamline will start in August 2019.

WEP096 **Magnetic Assessment of the First Apple X, the Prototype Undulator of the Athos Beamline**

***M. Calvi**, E. Ferrari, R. Ganter, C. Kittel, X.Y. Liang, T. Schmidt (PSI)*

Athos - the soft X-ray beamline of the SwissFEL user facility - will be equipped with Apple-X undulators to control the polarisation of the FEL radiation as well as to manipulate the K transversal gradient which is essential for the implementation of novel lasing modes. After recalling the essential features of these new undulators, the magnetic properties will be discussed following the new formalism developed for their modelling. Starting from the measurements of single magnets, the full procedure implemented for their magnetic assembling will be presented, including the design of the measurement bench. The results of the magnetic campaign will be reported: from the field optimisation up to the final characterisation, essential for the commissioning of the beam line. Finally, a short review about the status of the undulator production, including the modules for the EUXFEL, will close this contribution.

WEP097 **Operational Model of the Athos Undulator Beamline**

***C. Kittel**, M. Calvi, X.Y. Liang, T. Schmidt (PSI) N.J. Sammut (University of Malta, Information and Communication Technology)*

Athos, the new Soft X-ray beamline of SwissFEL, operates 16 Apple X undulators and 15 compact chicanes to implement novel lasing schemes. With the data available after the end of the magnetic measurement campaign (middle 2020), a self-consistent set of equations will be used to summarise all the relevant properties of those devices to start their commissioning. The analytical approach planned will be discussed in great details and tested with the preliminary experimental data available. Finally, the accuracy of this approach will be evaluated and critically compared to the requirements of the new FEL beamline.

WEP098 **Advanced Operational Models of the Apple X Undulator**

X.Y. Liang, *M. Calvi, C. Kittel, T. Schmidt (PSI) N.J. Sammut (University of Malta, Information and Communication Technology)*

Athos, the new soft X-ray beamline of the SwissFEL, will be equipped with Apple X undulators. These devices feature novel capabilities which require adequate models for their operation. The K-value and its gradient are calculated starting from the Fourier series of the magnetic field and they are expressed as a function of the classical parallel and anti-parallel modes - respectively elliptical and linear modes. The results are validated against computer simulations and compared to the magnetic measurements of the first Apple X prototype.

WEP099 **Design of Twin Helix Undulators for the NSRRC VUV Free Electron Laser**

C.-H. Chang, *C.H. Chang, T.Y. Chung, C.-S. Hwang, C.Y. Kuo, M.-C. Lin (NSRRC)*

Twin-helix undulators (THU) with a short period length of 20 mm and 24 mm have been designed for the NSRRC VUV free electron laser test facility. Four THU-20 undulators are needed for the FEL radiator and a THU-24 undulator is used for the modulator. These THU undulators consist of two helical magnet arrays symmetrically arranged along the beam axis. The THU-20 and THU-24 permanent magnet with helically shaped poles are designed and optimized to generate a high field of 1.0 T and 1.2 T respectively in a 5.6 mm diameter aperture along its axis. End pole design and shimming methods are considered to achieve very precise field performance in the small-bore diameter. Moreover, with a 0.5 mm space between two helical arrays, weak magnetic forces are tested in the THU-20 and THU-24 prototypes. A simple but precise mechanical support structure was designed for this horizontally open-gap undulator. To evaluate mechanical and magnetic properties of the magnet, short prototypes for the THU-20 and THU-24 were built and tested. This paper presents the magnetic design, mechanical techniques, and field measurement method for the THU undulators.

WEP100 **Conceptual Design of a Permanent Magnet Undulator for Fast Pulse-to-Pulse Polarization Switching in an FEL**

T.Y. Chung, *C.-S. Hwang (NSRRC)*

In this paper, we propose the design of an undulator to alter polarization at a fast frequency and the energy spectrum pulse-to-pulse in free-electron lasers (FELs). A fast time varying magnetic field generated in an undulator can alter characteristic light features. An electromagnetic (EM) and permanent magnet (PM) type undulator provides typically a magnetic field switching frequency below 100 Hz. Inductance and heating issues from coils limit the performance for the EM type and favor small magnetic fields and longer periods and for the PM type, strong magnetic forces between magnet arrays create undesired relative motion. In this paper, we discuss these issues and propose an undulator made of Halbach cylinders with rotating magnet arrays to switch the magnetic fields. Concept, magnet structure and performance are discussed in this note.

WEP101 **Polarisation Control via a Linear Delta Afterburner for the CompactLight Facility**

H.M. Castaneda Cortes, *D.J. Dunning, N. Thompson (STFC/DL/ASTeC)*

We studied the degree of polarisation of the FEL radiation from the diverted-beam scheme using the layout of the CompactLight facility, which is in the process of being designed. To satisfy the polarisation requirements defined by the users without compromising the aim of the facility to be compact, we studied a configuration comprising a helical Super Conductive Undulator (SCU) followed by a planar Delta afterburner. The trade-offs between the SCU length, afterburner length, degree of polarisation and output power are presented and discussed.

WEP102 **Design of Superconducting Helical Undulator for High Efficiency X-Ray FELs**

A.Yu. Smirnov, *R.B. Agustsson, I.I. Gadjev, S.M. Lynam, A.Y. Murokh (RadiaBeam) F.H. O'Shea (Elettra-Sincrotrone Trieste S.C.p.A.) C. Pellegrini (SLAC)*

There are now several operating vacuum ultraviolet to X-ray free-electron lasers (FEL) around the world and several more coming online, under construction, or proposed. Because of the tremendous amount of beam power at these facilities, they can produce ~50 GW of hard X-ray power in a ~100 fs long pulse. To break past this barrier in efficiency, we develop an Advanced Gradient Undulator (AGU), for which the simulated performance is multi-TW X-ray power at 8.3 keV. For a 10 fs pulse, this is a potentially 100-fold increase in X-ray intensity over state of the art X-ray FEL facilities. In this paper, we describe the advances of the AGU design from a number of parameters used in FEL simulations to a preliminary design for a bifilar superconducting undulator (λ_u = 2 cm and B = 1.6 T) with superimposed quadrupole field, and we also present the fabrication status of an undulator prototype.

WEP103 **A Plasma Attenuator for Soft X-Rays in LCLS-II**

A.S. Fisher, *A.L. Benwell, Y. Feng, B.T. Jacobson (SLAC)*

Attenuation of X-ray FEL beams is often required to avoid damaging optics and detectors during alignment, and to study fluence-dependent effects. Soft X-rays are commonly attenuated by photoabsorption in a gas such as argon. However, absorbing a mJ pulse along a meter creates a pressure wave that drives gas away from the X-ray propagation axis, until equilibrium recovers in ~1 ms. This timescale matched the 120-Hz pulse spacing of LCLS, but at the high repetition rate (up to 1 MHz) and power (up to 200 W) of LCLS-II, the attenuation of subsequent pulses is reduced. Simulations demonstrate hysteresis and erratic attenuation from gas-density depletion. Instead, we propose to replace the gas column with an argon plasma in a TM010 RF cavity. The density profile then is largely set by the RF mode. X-ray absorption becomes a perturbation compared to the energy in the plasma. An LCLS-II solid-state RF amplifier, generating up to 4 kW at 1.3 GHz, can provide the drive, and the FPGA-based low-level RF controller can be programmed to track tuning with plasma density. Several diagnostics are planned to monitor plasma properties over a fill-pressure range of 10 to 1000 Pa.

WEP104 A High-Power, High-Repetition Rate THz Source for LCLS-II Pump-Probe Experiments

***Z. Huang**, A.S. Fisher, M.C. Hoffmann, B.T. Jacobson, Z. Zhang (SLAC)*

Experiments using a THz pump and an X-ray probe at an X-ray free-electron laser (XFEL) facility like LCLS-II require frequency-tunable (3 to 20 THz), narrow bandwidth (~10%), carrier-envelope-phase-stable THz pulses that produce high fields (~MV/cm) at the repetition rate of the X-rays and well synchronized with them. In this paper, we propose a two-bunch scheme to generate THz radiation at LCLS-II: the first bunch produces THz radiation in a dedicated wiggler immediately following the undulator that produces soft X-rays from the second bunch. The initial time delay between the two bunches is optimized to compensate for the path difference in transport. We describe the THz wiggler and the transport system bringing the THz pulses from the wiggler to the experimental hall.

WEP105 Wavefront Shaping of X-Ray Free Electron Laser with Diffractive Optics

***Y. Liu**, D.T. Attwood, M. Chollet, K. Li, A. Sakdinawat, W.F. Schlotter, M.H. Seaberg, T. Weiss (SLAC) S. Marchesini (LBNL)*

Diffractive optics can be used to shape wavefronts of X-ray free-electron lasers (FEL), opening up new scientific opportunities. In this paper, we report the design and fabrication of X-ray diffractive optics for various applications with FELs. They include: Generation of ultrafast single shot hard X-ray (9.5 keV) orbital angular momentum beams at LCLS using diffractive optics. Multi-function diffractive optic-based high sensitivity X-ray absorption spectroscopy, approaching photon shot noise-limited measurements; New design algorithms and fabrication processes for illumination control using diffractive optics. Diamond-based grating beam splitter at 9.5 keV with tunable efficiency and high fidelity on wavefront (< lambda/100 aberration) for beam sharing and in-situ diagnostics at FEL beamlines.

WEP106 High Accuracy Wavefront Metrology for X-Ray Free Electron Lasers Using Single-Grating Talbot Interferometry

***Y. Liu**, Y. Ding, Y. Feng, D.M. Fritz, K. Li, G. Marcus, A. Sakdinawat, M.H. Seaberg, P. Walter (SLAC) L. Assoufid, W.C. Grizolli, X. Shi (ANL)*

The availability of intense, coherent X-rays from free-electron lasers (FELs) opens new opportunities for many areas of science and technology. Preserving the coherence and high quality wavefront of the X-ray beam is essential for many of the FEL applications. Here we report a robust, sensitive and accurate single-shot wavefront sensor for X-ray FEL beams using single grating Talbot interferometry. Experiments performed at the Linac Coherent Light Source (LCLS) demonstrate 3-sigma sensitivity and accuracy, both better than lambda/100, and retrieval of hard X-ray (9.5 keV) wavefronts in 3D. The technique was also extended to soft X-rays (500-1500 eV), using fractional Talbot plane configurations. The results provide valuable information to study the wavefront evolution from the FEL output, through beam transport optics and experimental instrument focusing optics, all the way to the sample. New accelerator science understanding of relationship between electron and photon beam under different undulator lengths and tapering is being studied. This wavefront sensor was selected as the standard and is currently being engineered for transition to LCLS and LCLS-II instruments.

WEP107 Polarizing Afterburner for the LCLS-II SXR Undulator Line

***H.-D. Nuhn** (SLAC)*

A fixed-gap polarizing undulator (Delta) has been successfully operated in afterburner mode in the LCLS FEL beamline at the SLAC National Accelerator Laboratory (SLAC) from August 2014 to the end of operations of the LCLS facility in December 2018. The LCLS undulator line is currently being replaced by two new undulator lines (as part of the LCLS-II project) to operate in the hard and soft X-ray wavelength ranges. Polarizing afterburners are planned for the end of the soft X-ray (SXR) line. A new polarizing undulator (Delta-II) is being developed for two reasons: (1) increased maximum K value to be resonant over the entire operational range of the SXR beamline (2) variable gap for K value control. It has been shown that using row phase control to reduce the K value while operating in circular polarizing mode severely degrades the performance of a polarizing undulator in afterburner mode. The device is currently scheduled for installation 2020-2021. The paper will explain the need for the variable gap design backed up by beam based measurements done with the LCLS Delta undulator.

WED — Wednesday - Late Afternoon

Chair: J. Grünert (EuXFEL)

WED01 16:15 30

Experience with Short-Period, Small Gap Undulators at the SwissFEL Aramis Beamline

***T. Schmidt**, M. Aiba, A.D. Alarcon, C. Arrell, S. Bettoni, M. Brügger, M. Calvi, E. Ferrari, R. Follath, R. Ganter, P.N. Juranič, C. Kittel, F. Löhl, E. Prat, S. Reiche, U.H. Wagner (PSI)*

The SwissFEL Aramis beamline provides hard X-ray FEL radiation down to 1 Angström with 5.8 GeV and short period, 15 mm, in-vacuum undulators (U15). To reach the maximum designed K-value of 1.8 the U15s have to be operated with vacuum gaps down to 3.0 mm. The thirteen-undulator modules are 4 m long and each of them is equipped with a pair of permanent magnet quadrupoles at the two ends, aligned magnetically to the undulator axis. Optical systems and dedicated photon diagnostics are used to check the alignment and improve the K-value calibration. In this talk the main steps of the undulator commissioning will be recalled and a systematic comparison between the magnetic results and the electron and photon based measurements will be reported to highlight achievements and open issues.

WED02 16:45 30

Absorbed Radiation Doses on the European XFEL Undulator Systems During Early User Experiments

***F. Wolff-Fabris**, J. Pflüger, H. Sinn (EuXFEL) W. Decking, D. Nölle, F. Schmidt-Föhre (DESY) F. Hellberg (Stockholm University)*

The EuXFEL is a FEL user facility based on a superconducting accelerator with high duty cycle. Three gap movable SASE Undulator Systems using hybrid NdFeB permanent magnet segments are operated. Radiation damage on undulators can impact the quality of the SASE process and ultimately threaten user operation. We observed in the commissioning phase doses up to 4 kGy and 3% demagnetization effect in a diagnostic undulator. Currently all SASE systems are used for user photon delivery and in this work we present characteristics of the absorbed radiation doses on undulators under stable conditions. Doses on the upstream segments are found to be originated in the event of occasional high energy electron losses. In contrast, towards the downstream end of a SASE system, individual segments show persistent absorbed doses which are proportional to the transmitted charge and are dominated by low energy radiation. This energy-dependence depiction shall result in distinct radiation damage thresholds for individual segments. Portable magnetic flux measurement systems allow in-situ tunnel assessment of undulator properties in order to estimate radiation dose limits for future user operation.

WED03 17:15 15

Pulse Resolved Photon Diagnostics at MHz Repetition Rates

***J. Grünert**, F. Dietrich, W. Freund, A. Koch, N.G. Kujala, J. Laksman, J. Liu, Th. Maltezopoulos, M.P. Planas (EuXFEL)*

The European X-ray Free Electron Laser (EuXFEL) enables a new era in the research of ultrafast dynamics of microscopic structures with atomic resolution. First light was demonstrated in May 2017 and operation started with three undulator beamlines and six experimental endstations with a commissioning phase from 2017 till early 2019. The world-wide unique feature of this machine is the combination of immensely brilliant and ultrashort X-ray pulses with a repetition rate in the MHz range. However, this also requires novel photon diagnostics to cope with these extreme conditions, to enable stable machine operation and to deliver beam diagnostic data to the users. In this contribution, we describe the results obtained in the commissioning and operation of the facility diagnostics capable of surviving exposure to multi-bunch operation and resolving the characteristics of individual pulses at MHz rates. In particular we employ for this task gas-ionization monitors, photoelectron spectroscopy of ionized noble gases, gated scintillator imaging, crystal spectrometers and arrival time monitors with fast line detectors, diamond detectors, and multi-channel plate based intensity monitors.

WED04 17:30 15

Undulator Adjustment with the K-Monochromator System at the European XFEL

***W. Freund**, J. Grünert, S. Karabekyan, A. Koch, J. Liu (EuXFEL) L. Fröhlich, D. Nölle, J. Wilgen (DESY)*

The SASE1 and SASE2 undulator systems of the European XFEL consist of 35 segments with variable-gap planar undulators which are initially tuned to precise on-axis magnetic field strengths in a magnetic measurement lab. After tunnel installation only photon based methods can determine the K-values of undulator segments with a similar accuracy. The spontaneous radiation of single or few undulator cells is spectrally filtered with the K-monochromator (K-mono) and recorded with a sensitive spontaneous radiation imager (SR-imager). By processing the images from the SR-imager and geometrical fitting of the spatial distribution of the spontaneous radiation we obtain very fast the K-parameter and the beam pointing of single segments. This information is used for adjustments of the gap settings and vertical offset positions of the single undulator segments. In this presentation we describe the K-mono system at the European XFEL, the measurement principle, and the measurements that were performed.

WET — Wednesday Tutorial

WET01 18:00 60

Photon Transport Beamline Design

H. Sinn *(EuXFEL)*

Free Electron Lasers produce X-ray light with almost perfect coherence. The optical elements of the beam transport system have to fulfill therefore much more stringent - and in part also different - specifications compared to similar optics at synchrotron radiation sources. Another aspect of X-ray laser light is that it is generated in very intense and short pulses, which leads to the effect that the heat pile-up in anything intercepting the beam and can outrun the thermal transport on different time scales. This poses strong limitations on the suitable materials that can be used for mirror coatings, slits, attenuators and absorbers. Under certain conditions the beam can drill very fast through thick slabs of material, which opens up new possibilities for technical applications but poses also new challenges to the radiation safety system. This tutorial gives an overview of the basic relations needed to understand the physics of X-ray optics at free electron lasers and illustrates also experiences from the first two years of operation of the European XFEL.

THA — Thursday - Early Morning

Chair: Y.U. Jeong (KAERI)

THA01 09:00 30 **Serial Femtosecond Crystallography at MHz XFELs**

M.L. Grünbein *(Max Planck Institute for Medical Research)*

The new megahertz (MHz) X-ray free-electron lasers (XFEL) promise data collection in an extremely rapid and sample-efficient manner. However, this can only hold true under the condition that pristine sample is provided at a rate commensurate to the XFEL pulse rate, imposing severe constraints on sample delivery. Liquid jet injection is ideally suited for this task and the method of choice for biological samples. However, the high intensity of the XFEL pulse not only allows to capture diffraction data from tiny samples, but it subsequently also destroys the exposed sample in the jet. The energy deposited by the XFEL beam results in an explosion, generating a gap in the liquid jet transporting the sample. Moreover, a shock wave is launched, propagating along the jet and producing ns-long pressure jumps on the order of 0.1-1 GPa, possibly affecting the sample. We will discuss recent experiments performed at European XFEL, demonstrating that meaningful data collection of unaffected sample is possible at 1 MHz repetition rate as well as findings and implications from serial femtosecond crystallography experiments performed at the LCLS using much higher X-ray repetition rate.

THA02 09:30 30 **Searching for the Hypothesized Liquid-Liquid Critical Point in Supercooled Water with X-Ray Free Electron Laser**

K.H. Kim *(POSTECH) K. Amann-Winkel (FYSIKUM, AlbaNova, Stockholm University) A. Nilsson (Stockholm University)*

Water is the most important liquid for our existence on Earth and plays an essential role in physics, chemistry, biology, and geoscience. In the liquid form, water has numerous anomalous properties as compared to other liquids such as density maximum at 4-degree C. As an explanation for these anomalous experimental observations, a hypothetical liquid-liquid transition (LLT) and a liquid-liquid critical point (LLCP) has been proposed deep in the supercooled regime. Recently a new method of rapid cooling and ultrafast probing with wide-angle X-ray scattering (WAXS) using FELs (LCLS, SACLA, and PAL-XFEL) has allowed the venture into no man's land and we found the first experimental evidence of the existence of the Widom line which is supposed to emanate from the LLCP. By introducing optical pulse to the setup, pump-probe type measurements are also possible to study the liquid-liquid transition.

THA03 10:00 30 **IR-FEL Project at the cERL and Future EUV-FEL Lithography**

R. Kato*, Y. Honda, H. Kawata, T. Miyajima, N. Nakamura, H. Sakai, M. Shimada, Y. Tanimoto, K. Tsuchiya (KEK)*

Recently KEK has launched an infrared FEL project with a competitive funding from NEDO (New Energy and Industrial Technology Development Organization). The purpose of this project is to build a mid-infrared FEL at the compact Energy Recovery Linac (cERL), and to use that FEL as a light source for construction of the processing database required for industrial lasers. The FEL system is composed of two 3 m undulators and a matching section between them, and generates light with a maximum pulse energy of 1 μJ at the wavelength of 20 μm with an 81.25 MHz repetition rate. The FEL is also expected to become a proof-of-concept machine for ERL base FELs for future EUV lithography. The detail of the project will be presented, and the relationship of the technical development between the mid-infrared FEL and the future EUV-FEL will be discussed.

THA04 10:30 15 **Ultrafast Magnetization Dynamics at the Low-Fluence Limit Supported by External Magnetic Fields**

M. Riepp*, T. Golz, G. Grübel, L. Müller, A. Philippi-Kobs, W.R. Roseker, R. Rysov, N. Stojanovic, M. Walther (DESY) F. Capotondi, M. Kiskinova, D. Naumenko, E. Pedersoli (Elettra-Sincrotrone Trieste S.C.p.A.) R. Frömter, H.P. Oepen (University of Hamburg, Institut für Experimentalphysik)*

We report on demagnetization upon infrared (IR) laser excitation of nanometer magnetic multidomain systems on the sub-picosecond timescale by employing time-resolved magnetic small angle X-ray scattering (tr-mSAXS) at the DiProI beamline of FERMI@Elettra. Few repetition Co/Pt multilayers were pumped by circularly polarized 3.5 ps long IR pulses with a fluence of 3.4 mJ/cm^2 to study demagnetization in the framework of all-optical switching. The magnetic state was probed by 20.8 nm wavelength FEL pulses triggering resonant electronic transitions at the M2,3 absorption edge of cobalt. Small magnetic fields of up to 25 mT parallel to the sample's magnetization direction have been applied in order to induce a preferred magnetic orientation with regard to the pump-pulses' polarization. By employing tr-mSAXS at FERMI's DiProI beamline we have not only been able to follow the demagnetization process on a sub-picosecond timescale but also field dependent domain rearrangements governing ultrafast demagnetization have been observed.

THB — Thursday - Late Morning

Chair: S. Bettoni (CERN)

THB01 11:15 30

Using an E-SASE Compression to Suppress Microbunch Instability and Resistive-Wall Wake Effects

P.M. Anisimov *(LANL)*

High brightness electron sources, such as photo injectors, deliver electron beams with a few Ampere peak currents yet high energy X-ray free-electron lasers require electron beams with >3kA peak currents to operate. In order to bridge this gap, a 100x beam compression that does not reduce the brightness of an electron beam has to take place. We will present our study of an E-SASE based compression scheme aimed at satisfying the requirements of high energy X-ray free electron lasers regarding electron beam currents, energy spreads and emittances. The E-SASE compression is based on a laser modulation of an electron beam energy and subsequent compression in a small magnetic chicane, which results in a train of high current bunches that are synchronized to the external laser and could be used in pump-probe experiments. A unique time profile of an electron beam is expected to suppress the resistive-wall wake effects.

THB02 11:45 30

Understanding 1-D to 3-D Coherent Synchrotron Radiation Effects

A.D. Brynes *(STFC/DL/ASTeC)*

Collective effects such as coherent synchrotron radiation (CSR) can have a strong influence of the properties of an electron bunch with respect to the quality of the FEL light that it produces. In particular, CSR experienced by a bunch on a curved trajectory can increase the transverse emittance of a beam. In this contribution, we present an extension to the well-established 1D theory of CSR by accounting fully for the forces experienced in the entrance and exit transients of a bending magnet. A new module of the General Particle Tracer (GPT) tracking code was developed for this study, showing good agreement with theory. In addition to this analysis, we present experimental measurements of the emittance growth experienced in the FERMI bunch compressor chicane as a function of bunch length. When the bunch undergoes extreme compression, the 1D theory breaks down and is no longer valid. A comparison between the 1D theory, experimental measurements and a number of codes which simulate CSR differently are presented, showing better agreement when the transverse properties of the bunch are taken into account.

THB03 12:15 15

Emittance Measurements and Minimization at SwissFEL

E. Prat*, M. Aiba, S. Bettoni, P. Craievich, P. Dijkstal, E. Ferrari, R. Ischebeck, F. Löhl, A. Malyzhenkov, G.L. Orlandi, S. Reiche, T. Schietinger (PSI)*

The transverse emittance of the electron beam is a fundamental parameter that determines the performance of free-electron-lasers (FELs). In this contribution, we present emittance measurements carried out at SwissFEL, the X-ray FEL facility that recently started to operate at PSI in Switzerland, including a description of our measurement methods and optimization procedures. We obtained slice emittance values at the undulator entrance down to ~200 nm for an electron beam with a charge of 200 pC and an r.m.s. duration of ~30 fs. Furthermore, we achieved slice emittances as low as ~100 nm for 10 pC beams with few femtosecond duration.

THB04 12:30 15

Longitudinal Phase Space Study on Injector Beam of High Repetition Rate FEL

Q. Gu *(SSRF) Z. Wang (SARI-CAS)*

The longitudinal phase space of the high repetition rate injector beam usually twisted and deteriorated by the space charge force. It causes the correlated energy spread and the local chirp within the beam, which could not compensated by the harmonic correction. As a consequence of this problem, one could not get ideal beam with a peak current more than kiloamperes. In this paper several approaches have been studied to relieve this effect and get the well compressed beam for the lasing.

THP — Thursday Poster Session

THP001 **Steffen Hard-Edge Model for Quadrupoles with Extended Fringe-Fields for Linear Beam Optics of the European XFEL**

***N. Golubeva**, V. Balandin, W. Decking, L. Fröhlich, M. Scholz (DESY)*

For modeling of linear focusing properties of quadrupole magnets the conventional rectangular model (with constant field gradient inside of the effective quadrupole length) is commonly used for the design and calculations of the linear beam optics for accelerators. For the linear optics of the European XFEL the quadrupole magnets are described using a more accurate Steffen hard-edge model. In this paper we discuss the application of Steffen model for the XFEL quadrupoles and present the verification of beam optics model with the measurements of orbit response matrices.

THP002 **Beam Based Alignment in All Undulator Beamlines at European XFEL**

***M. Scholz**, W. Decking (DESY) Y. Li (EuXFEL)*

The Free Electron Laser European XFEL aims at delivering X-rays from 0.25 keV up to 25 keV out of three SASE undulators. A good overlap of photon and electron beams is indispensable to obtain good lasing performance, especially for the higher photon energies. Thus the quadrupole magnets in the undulators must be aligned as good as possible on a straight line. This can only be realized with a beam based alignment procedure. In this paper we will report on the method that was performed at the European XFEL. We will also discuss our results.

THP003 **Arbitrary Order Perturbation Theory for a Time-Discrete Model of Micro-Bunching Driven by Longitudinal Space Charge**

***Ph. Amstutz** (LBNL) , M. Vogt (DESY)*

A well established model for studying the micro-bunching instability driven by longitudinal space charge in ultra-relativistic bunches in FEL-like beamlines can be identified as a time-discrete Vlasov system with general drift maps and Poisson type collective kick maps. Here we present an arbitrary order perturbative approach for the general system and the complete all-orders solution for a special example. For this example we benchmark our theory against our Perron-Frobenius tree-code.

THP004 **A Tree-Code for Efficiently Representing and Evolving Exotic Phase Space Densities with Application to Micro-Bunching in FEL-like Beamlines**

***Ph. Amstutz** (LBNL) , M. Vogt (DESY)*

The supports of phase space densities as are typically encountered in FEL beamlines are shaped by strong nonlinearities and strong coherent effects. Thus these supports can have quite exotic shapes and can therefore often not be represented efficiently on standard regular meshes. We present a c++ class library for (a): setting up an adaptive (in principle n-dimensional) tree-grid that discretizes phase space with highest resolution only where densities are non-neglibible; and (b): propagating these densities by virtue of a Liouville/Vlasov evolution while adapting the grid to follow the support of the densities. Furthermore we present an application of this library that simulates LSC driven micro-bunching in FEL like beamlines. We benchmark our code against the explicit solution of a solvable non-trivial micro-bunching example.

THP005 **Refurbishment and Upgrade Plans for FLASH for the Years After 2020**

***M. Vogt**, K. Honkavaara, J. Rönsch-Schulenburg, S. Schreiber, J. Zemella (DESY)*

FLASH is a unique superconducting soft X-ray FEL capable of producing up to 8000 photon pulses per second. A refurbishment program is ongoing. In addition a substantial upgrade is planned to keep FLASH attractive and competitive. The current state of the update plan will be discussed.

THP006 **Optics & Compression Schemes for the FLASH 2020+ Upgrade Program**

***J. Zemella** (DESY)*

The proposed FLASH upgrade (FLASH 2020+) will rely on high quality electron beams provided to all undulator beamlines. Here we describe possible modifications to the FLASH lattice and the compression scheme that aim at improving the beam quality and the ability to control critical beam properties along the machine - simultaneously and independently for all beamlines.

THP007 **Frequency Detuning Dependent Transient Coaxial RF Coupler Kick**

***Y. Chen**, J.D. Good, M. Groß, I.I. Isaev, C. Koschitzki, M. Krasilnikov, S. Lal, X. Li, O. Lishilin, G. Loisch, D. Melkumyan, R. Niemczyk, A. Oppelt, H.J. Qian, H. Shaker, G. Shu, F. Stephan, G. Vashchenko (DESY Zeuthen) F. Brinker, W. Decking (DESY)*

We model and characterize a transverse kick which results from the coaxial RF coupler in the L-band RF gun at the Photo Injector Test Facility at DESY in Zeuthen (PITZ). The RF pulse is typically 600 μs long and used to produce a train of up to 2700 electron bunches. The kick is transient and found to be dependent on the detuning of the resonance frequency of the gun cavity. The frequency detuning within the RF macro-pulse results in a variation in the kick strength along the pulse. This leads to a downstream orbit and size change of individual bunches within the train. Using 3D RF field distributions calculated at detuned frequencies of the cavity, particle tracking simulations are performed to simulate the transient kick onto the bunch train. Given a drift distance, the orbit and size change along a train of fixed length is estimated. Systematic measurements of the kick have meanwhile been carried out. The temperature of the cooling water for the gun is tuned allowing detailed characterization of the frequency detuning within the RF pulse, and thereby measurements of the kick under conditions of practical interest. Experimental findings and simulation results will be presented.

THP008 Design of a Multi-Cell SRF Reduced-Beta Cavity for the Acceleration of Low Energy Electron Beams

D.B. Bazyl, *H. De Gersem, W.F.O. Müller (TEMF, TU Darmstadt) J. Enders, S. Weih (TU Darmstadt)*

Recently, the S-DALINAC has successfully passed the first ERL tests. One of the critical requirements for further operation in the ERL regime is minimising the longitudinal energy spread of the electron beam. One of the major sources for the current energy spread at the S-DALINAC is the low energy accelerating section. In order to overcome this problem an SRF reduced-beta cavity has been designed. The new cavity will replace the existing capture section and will allow to accelerate low energy electron beams with a minimised energy spread growth. In this work we discuss the electromagnetic and mechanical design of the SRF 3 GHz 6-cell reduced-beta cavity of elliptic type. In addition, we present the results of beam dynamics simulations.

THP009 Space Charge Beam Dynamics Simulations for THz-FEL Undulators

S.A. Schmid, *H. De Gersem, E. Gjonaj (TEMF, TU Darmstadt)*

The THz SASE FEL at DESY-PITZ will operate at 16.7 MeV beam energy with particle bunch charges up to 4 nC. In this operation mode, space charge interaction strongly influences the dynamics of the low energy electron bunch inside the undulator. Hence, space charge beam dynamics simulations are a very important aspect of THz-FEL design studies. Many beam dynamics codes use simplified electrostatic space charge models in the Lorentz transformed rest frame of the particle bunch. However, this approach does not include retardation effects for particle beams on oscillatory trajectories. Furthermore, synchrotron radiation generated by the oscillating particles will influence the beam dynamics. In this contribution, we investigate the beam dynamics in the THz undulator of DESY-PITZ and analyze the effects of retardation and radiation fields for different operation conditions of the undulator. Furthermore, the validity of the underlying numerical models with respect to physical completeness and runtime performance is discussed.

THP010 Simple and Robust Free-Electron Laser Doubler

S. Di Mitri, *G. De Ninno, R. Fabris, S. Spampinati (Elettra-Sincrotrone Trieste S.C.p.A.) G. De Ninno (University of Nova Gorica) N. Thompson (STFC/DL/ASTeC) N. Thompson (Cockcroft Institute)*

We present the design of a Free-Electron Laser (FEL) doubler suitable for the simultaneous operation of two FEL lines. The doubler relies on the physical selection of two longitudinal portions of an electron bunch at low energy, and on their spatial separation at high energy. Since the two electron beamlets are naturally synchronized, FEL pump-FEL probe experiments are enabled when the two photon pulses are sent to the same experimental station. The proposed solution offers improved flexibility of operation w.r.t. existing two-pulse, two-color FEL schemes, and allows for independent control of the color, timing, intensity and angle of incidence of the radiation pulses at the user end station. Detailed numerical simulations demonstrate its feasibility at the FERMI FEL facility.

THP011 Experimental Benchmarking of Wakefields at the FERMI FEL Linac and Undulator Line

S. Di Mitri, *L. Sturari (Elettra-Sincrotrone Trieste S.C.p.A.) C. Venier, R. Vescovo (University of Trieste)*

Collective effects such as wakefields affect the dynamics of high brightness electron beams in linear accelerators (linacs), and can degrade the performance of short wavelength free-electron lasers (FELs). If a reliable model of wakefields is made available, the accelerator can be designed and configured with parameters that minimize their disrupting effect. In this work, the simulated effect of geometric (diffractive) wakefields and of coherent synchrotron radiation on the electron beam energy distribution at the FERMI FEL is benchmarked with measurements, so quantifying the accuracy of the model. Wakefields modelling is then extended to the undulator line, where particle tracking confirms the limited impact of the resistive wall wakefield on the lasing process. The study reveals an overall good understanding of collective effects in the facility.

THP012 Compact FEL-Driven Inverse Compton Scattering Gamma-Ray Source

M. Placidi, *G. Penn (LBNL) , S. Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.) C. Pellegrini (UCLA) C. Pellegrini (SLAC)*

We explore the feasibility of a compact source of quasi-monochromatic, multi-MeV gamma-rays based on Inverse Compton Scattering (ICS) from a high intensity ultra-violet (UV) beam generated in a free-electron laser by the electron beam itself. This scheme introduces a stronger relationship between the energy of the scattered photons and that of the electron beam, resulting in a device much more compact than a classic ICS for a given scattered energy. The same electron beam is used to produce gamma-rays in the 10^{-20} MeV range and UV radiation in the 10^{-15} eV range, in a ~4x22 m2 footprint system.

THP013 User Operation of Sub-Picosecond THz Coherent Transition Radiation Parasitic to a VUV FEL

S. Di Mitri, *N. Adhlakha, E. Allaria, L. Badano, G. De Ninno, P. Di Pietro, G. Gaio, L. Giannessi, G. Penco, A. Perucchi, P. Rebernik Ribič, E. Roussel, S. Spampinati, C. Spezzani, M. Trovò, M. Veronese (Elettra-Sincrotrone Trieste S.C.p.A.) G. De Ninno (University of Nova Gorica) L. Giannessi (ENEA C.R. Frascati) S. Lupi (Coherentia) S. Lupi (Sapienza University of Rome) F. Piccirilli (IOM-CNR) E. Roussel (PhLAM/CERCLA)*

Coherent transition radiation is enhanced in intensity and extended in frequency spectral range by the electron beam manipulation in the beam dump beam line of the FERMI FEL, by exploiting the interplay of coherent synchrotron radiation instability and electron beam optics. Experimental observations at the TeraFERMI beamline confirm intensity peaks at around 1 THz and extending up to 8.5 THz, for up to 80 μJ pulse energy integrated over the full bandwidth. By virtue of its implementation in an FEL beam dump line, this work might stimulate the development of user-oriented multi-THz beamlines parasitic and self-synchronized to VUV and X-ray FELs.

THP014 **Mode Expansion Method Applied to the Calculation of Space Charge Impedance**
D. Zhou *(KEK)*
The fields generated by a point charge moving parallel to the axis of a rectangular chamber can be calculated using the mode expansion method. In combination with the impedance theory, the Green-function form of the impedance driven by a point charge can be formulated. Consequently, the wakefields of a beam with various distributions can be computed numerically. This paper summarizes our findings and also show comparisons to the existing theories.

THP015 **The X-Band Linear Compression System in Dalian Coherent Light Source**
***Y. Yu**, Z. Chen, G.K. Cheng, D.X. Dai, H.L. Ding, Z.G. He, L. Huang, Q.M. Li, Z.B. Li, L. Shi, J.T. Sun, K. Tao, Y.H. Tian, G.L. Wang, Z.Q. Wang, G.R. Wu, J.Y. Yang, X.M. Yang, W.Q. Zhang (DICP)*
Dalian Coherent Light Source (DCLS) is a free-electron laser (FEL) facility working in the extreme ultraviolet (EUV) wavelength region from 50 to 150 nm, it mainly operates on the High Gain Harmonic Generation (HGHG) mode with the seed laser wavelength ranging from 240 to 360 nm, although it can also run in Self Amplified Spontaneous Emission (SASE) mode. As with other FELs, in order to acquire high-quality FEL radiation, the excellent electron bunch is needed, including the transverse and longitudinal properties, such as small normalized transverse emittance, proper electron bunch energy, small energy spread, especially high and flat peak current. Due to the nonlinearity of sinusoidal accelerated microwave and the second order compression factor T566 of bunch compressor, the high and flat peak current cannot be achieved when the electron bunch is compressed, so we are planning to install an X-band decelerated tube working on the fourth harmonic of the accelerator microwave before the bunch compressor. This paper focuses on the beam dynamics design of the linear bunch compression of DCLS, and the simulation results by Elegant and the analysis will be presented.

THP016 **Study of Microbunching Instability in SHINE Linac**
D. Huang *(SINAP)*
The SHINE project in China aims at the next generation high repetition rate and high power hard X-ray free electron laser facility. The high quality electron beam is thus requested in the linac to generate such a high quality FEL lasing. As the prerequisite, the microbuncing instability introduced by the nonlinear effects such as the LSC, CSR and wakefields in the bunch compressing process must be taken care of, otherwise the electron beam will not meet the requirements of lasing. In this article, the microbunching effects including the gain of the instability in the linac of SHINE are estimated, and several ways for the control of the instability are proposed.

THP017 **Large Bandwidth X-Ray Free Electron Laser Operation Mode of SXFEL User Facility**
***J.W. Yan**, H.X. Deng (SINAP) H.X. Deng (SARI-CAS)*
In recent years, the large-bandwidth XFEL operation schemes are proposed for X-ray spectroscopy and X-ray crystallography, in which overcompression is a promising scheme to produce broad-bandwidth XFEL pulses through increasing the electron beam energy chirp. In this work, finding out the overcompression working point of the linac is treated as a many-objective (having four or more objectives) optimization problem, thus the nondominated sorting genetic algorithm III (NSGA-III) is applied to the beam dynamic optimization for the first time. Start-to-end simulations demonstrate a full bandwidth of 4.79% for the Shanghai soft X-ray free-electron laser user facility.

THP018 **Deflecting Cavity Dynamics for Time-Resolved Machine Studies of SHINE**
***J.W. Yan**, H.X. Deng (SINAP) H.X. Deng (SARI-CAS)*
Transverse deflecting structures (TDS) have been widely used in modern free electron laser facilities for longitudinal phase space diagnostics of electron beams. To achieve high resolution, the optics of the deflecting structure should be well optimized. In this paper, the evolutionary algorithm is introduced to optimize the optics of the deflecting structure of SHINE after the undulator. In addition, we propose to separate electron beams in high repetition rate through adjusting the phase of the TDS.

THP019 **Single Particle Dynamics of Microbunching**
X.J. Deng *(TUB)*
Microbunching is and will continue in the years to come to be one of the accelerator physics research focus. Though the great power of microcbunching is from collective effects, a systematic investigation of related single particle effects will be of value to better benefiting from microbunching. In this paper we review and reinvestigate the single particle dynamics of microbunching with emphasis on their manifestation and importance in CHG, bunch slicing and FEL in which precision manipulations of longitudinal phase space are involved.

THP020 **Microbunching Enhancement by Adiabatic Trapping**
***X.J. Deng**, W.-H. Huang, C.-X. Tang (TUB) A. Chao (SLAC)*
In this paper, microbunching enhancement techniques making use of the adiabatic trapping mechanism are reviewed with some new examples presented. The applications of these techniques to FEL and IFEL research are emphasized.

THP022 **Longitudinal Strong Focusing and High Harmonic Generation**
***Y. Zhang**, X.J. Deng, C.-X. Tang, C.-X. Tang (TUB)*
A new method for bunch compression based on transverse and longitudinal coupling is proposed. Using this method, an electron beam can be compressed to several tens of nanometers. And hence a high harmonic radiation with much better temporal coherence can be generated.

THP023 RF Kick of Superconducting Nine-Cell 1.3 GHz Cavity

J.J. Guo *(University of Chinese Academy of Sciences) Q. Gu (SINAP) Q. Gu (SSRF)*

Shanghai high-repetition-rate XFEL and extreme light facility (SHINE), the first hard XFEL based on a superconducting accelerated structure in China, is now under development at the Shanghai Institute of Applied Physics, Chinese Academy of Sciences. Superconducting TESLA-type cavities are widely used to accelerate electrons in long bunch trains, such as in high repetition rate free electron lasers. The TESLA cavity is equipped with two higher order mode couplers and a fundamental power coupler (FPC), which break the axial symmetry of the cavity. The passing electrons therefore experience axially asymmetrical coupler kicks, which depend on the transverse beam position at the couplers and the RF phase. The resulting emittance dilution has been studied in detail in the literature. However, the kick induced by the FPC depends explicitly on the ratio of the forward to the backward traveling waves at the coupler, which has received little attention. Particular attention is directed to the role of the penetration depth of the FPC antenna, which determines the loaded quality factor of the cavity.

THP024 Spontaneous Coherent Radiation of Stabilized Dense Electron Bunches

Yu.S. Oparina*, V.L. Bratman, A.V. Savilov (IAP/RAS) N. Balal, Yu. Lurie (Ariel University)*

Modern sources of dense electron beams allow the formation of compact sources of dense electron bunches with energies of 3-6 MeV, ps pulse durations, and charges of up to 1 nC. Such bunches can be used for the realization of relatively simple and compact powerful terahertz sources based on spontaneous coherent radiation. The power and duration of the process of such type of emission are limited due to an increase in the bunch length under the Coulomb repulsion. This complicates the effective implementation of the regime of spontaneous coherent radiation for dense bunches. Therefore, special methods for stabilization of the length of the operating e-bunch during its motion over a long electron-wave interaction region should be used. We propose several methods of the stabilization based on the axial bunch compression by self-radiated wave fields and by quasi-static Coulomb fields inside a bunch. The latter takes place in the case of the motion of electrons through the undulator in the "negative-mass" regime, when the Coulomb field inside the bunch leads not to repulsion of electrons but to their mutual attraction.

THP025 Radiation Energy Loss in Planar Undulator and Spectra Simulation Features

N.V. Smolyakov *(NRC)*

A relativistic electron passing through an undulator generates electromagnetic radiation at the expenses of its own kinetic energy. This effect is usually not taken into account if the number of periods of the undulator is relatively small, that is about 100 - 200. However, at FEL facilities, long installations have been built, where many undulators are installed one after another and a number of undulator periods in total range up to thousand or even more. In this case, because of the electron energy decrease along its trajectory, the radiation from different undulators will drop out of synchronism. As a result, the radiation spectral line will be much wider unless special corrective actions are taken to compensate the energy loss effect (undulators tapering). In the presented report, this effect was analyzed analytically and numerically. An expression for the critical number of undulator periods, when the effect of electron energy loss should be properly taken into account, is derived. It was shown here that the formal employment of expressions, initially derived for the fixed electron energy, can produce mistaken results.

THP026 Electron Trajectories in Sinusoidal Three-Dimensional Field of Planar Undulator

N.V. Smolyakov *(NRC)*

It is well-known that the electron trajectory in an undulator is influenced by the focusing properties (both horizontal and vertical) of the magnetic field. The approximate solutions of motion equations for electrons in the 3-dimensional magnetic field, which describe these focusing properties, can be found by means of averaging over the short-length oscillations. On the other hand, the equations of motion can be solved numerically, by applying the Runge-Kutta algorithm. It is shown in this paper that numerically computed trajectories, which can be considered as figure of merit, on frequent occasions differ considerably from the correspondent approximate solutions obtained through the averaging method. It means that actually the undulator field influence on the electron trajectory is complicated and often cannot be reduced to the well-known focusing phenomena along.

THP027 Simulation and Optimization of the Transport Beamline for the NovoFEL RF Gun

A.S. Matveev*, I.V. Davidyuk, O.A. Shevchenko, V.G. Tcheskidov, N.A. Vinokurov, V. Volkov (BINP SB RAS) I.V. Davidyuk,* ***A.S. Matveev****, N.A. Vinokurov (NSU)*

A new low-frequency CW RF gun was developed and tested at Budker Institute of Nuclear Physics recently. We plan to use it to upgrade the ERL of the Novosibirsk FEL facility. It will allow increasing the average beam current (due to higher beam repetition rate) and thus increasing the average radiation power. The transport beamline for the RF gun uses the ninety-degree achromatic bend. It is designed in a way that keeps an option to operate with the old electrostatic gun as well. Due to the low beam energy (290 keV) the beam dynamics is strongly influenced by space-charge forces. The paper describes results of simulation and optimization of the RF gun transport beamline. Space-charge forces were taken into account with the code ASTRA. Main sources of emittance degradation were considered in order to decrease their influence during the optimization. In addition, the RF gun output beam parameters were measured for various RF gun emission phases. These experiments were simulated and the results were compared. The resulting beam parameters meets requirements of the Novosibirsk FEL facility ERL.

THP028 **Laser Heater Commissioning at the SwissFEL Facility**

S. Bettoni, *A. Dax, E. Ferrari, M. Huppert, A. Trisorio, C. Vicario (PSI)*

Shot noise or an initial intensity modulation in the beam pulse may have a strong effect in the Free Electron Laser (FEL) linacs and also severely degrade the machine performances in terms of FEL performances. This instability may be triggered by a shot-noise mechanism and/or by some initial modulations at the generation of the electron bunch, and amplified in the machine. The laser heater is the device typically used to mitigate this instability. We discuss the recent commissioning of this device at SwissFEL, the FEL facility at the Paul Scherrer Institut. We present both the characterization of the electron beam and the effect on the lasing performances as well.

THP029 **Considerations of Orbit Control and Optical Function Measurement for the Proposed NSRRC VUV FEL Test Facility**

C.H. Chen, *H.P. Hsueh, W.K. Lau, A.P. Lee (NSRRC)*

A driver linac system with dogleg bunch compressor has been designed for the proposed NSRRC seeded VUV FEL test facility. However, performance of the dogleg compressor is considered to be sensitive to alignment errors and imperfection of magnetic fields. A number of stripline-type beam position monitors, orbit corrector magnets and sreen monitors will be installed along the beamline for monitoring and steering. Simulation results of orbit correction with MAD showing that the satisfactory orbit control can be obtained under certain errors. Considerations of orbit control and optical function measurements for this linac system will be discussed.

THP030 **An Updated Design of the NSRRC Seeded VUV Free Electron Laser Test Facility**

W.K. Lau, *C.K. Chan, C.-H. Chang, C.-C. Chang, C.H. Chen, M.C. Chou, P.J. Chou, F.Z. Hsiao, K.T. Hsu, H.P. Hsueh, K.H. Hu, C.-S. Hwang, J.-Y. Hwang, J.C. Jan, C.K. Kuan, A.P. Lee, M.-C. Lin, G.-H. Luo, K.L. Tsai (NSRRC) A. Chao, J. Wu (SLAC) S.Y. Teng (NTHU)*

Limited by the NSRRC Accelerator Test Area (ATA) tunnel length, previous design of the VUV free electron laser (FEL) test facility has to be modified. In this report, we present a new design of the facility which is a 200-nm seeded, fourth harmonic HGHG FEL driven by a 250 MeV high brightness electron linac system with dogleg bunch compressor that aimed to generate ultrashort intense coherent radiation in the vacuum ultraviolet region. It employs helical undulators for enhancement of laser-beam interaction in the modulator and radiator to produce hundreds of MW VUV radiation with wavelength as short as 50 nm from a THU20 twin helical undulator of 20-mm period length. A 200-nm seed laser for beam energy modulation in the periodic magnet field of a THU24 undulator and micro-bunching is accomplished by a 'small chicane' before the beam is sent to THU20. The facility layout and FEL output performance will be reported.

THP031 **Simulation and Optimization of Electron Beam Properties for Generation of a Pre-bunched THz Free Electron Lasers**

N. Chaisueb, *S. Rimjaem (Chiang Mai University) S. Rimjaem (ThEP Center, Commission on Higher Education)*

A linac-based light source for generation of infrared free electron lasers (FELs) has been designed and developed at the Plasma and Beam Physics Research Facility, Chiang Mai University, Thailand. The injector system of the facility consists mainly of an S-band thermionic cathode RF gun, a pre-bunch compressor in the form of an alpha magnet and a travelling-wave linac structure. Due to the space limitation, two 180-degree achromat systems are used to turn around the beam and also utilized as a post magnetic bunch compressor. Two separate beamlines are followed these two achromat systems. The first beamline is for generation of MIR FEL and the other is for generation of THz FEL. In this work, we focus only on the coherent and high-power THz undulator radiation. Thus, this can be called as the pre-bunched THz FEL. Design of the injector system and the magnetic bunch compressor are conducted to obtain the optimal electron beam properties at the undulator entrance. Start-to-end beam dynamic simulations using ASTRA code to optimize electron beam parameters are performed and presented in this paper.

THP032 **A CSR Model Based on Retarded LW Potentials**

S.B. van der Geer, *M.J. de Loos (Pulsar Physics) A.D. Brynes, P.H. Williams (STFC/DL/ASTeC) S. Di Mitri (Elettra-Sincrotrone Trieste S.C.p.A.) I. Setija (ASML Netherlands B.V.)*

For future applications of high-brightness electron beams, including the design of next generation FEL's, correct simulation of Coherent Synchrotron Radiation (CSR) is essential as it potentially degrades beam quality to unacceptable levels. However, the long interaction lengths compared to the bunch length, numerical cancellation, and difficult 3D retardation conditions make accurate simulation of CSR effects notoriously difficult. To ease the computational burden, CSR codes often make severe simplifications such as an ultra-relativistic bunch travelling on a prescribed reference trajectory. Here we report on a CSR model implemented in the General Particle Tracer (GPT) code that avoids most of the usual assumptions: It directly evaluates the Liénard-Wiechert potentials based on the stored history of the beam. It makes no assumptions about reference trajectories, takes into account the transverse size of the beam, and supports rollover compression.

THP033 **Compact Isochronous Chicanes for XFEL Applications**

N. Thompson *(STFC/DL/ASTeC)*

FEL schemes such as High-Brightness SASE and Mode-Locking require electron beam delays inserted between undulator sections. These schemes have been shown in simulations to perform most effectively when the electron beam delays are very close to isochronous, i.e. the first order longitudinal dispersion is very small. To minimise the disruption to the FEL process in the inter-undulator gaps, these delays must also be as compact as possible. In this paper we study the maximum longitudinal space that a delay chicane could occupy in an XFEL operating at 6 GeV before the peak power drops below a defined threshold, and we present a limit for the maximum longitudinal dispersion of the delay chicanes. We then present the optical designs of two chicanes that satisfy the requirements of length and isochronicity and show how these designs could be realised practically using small-aperture high-field quadrupoles.

THP034 **Laser Shaping for Microbunching Instability Suppression and Seeded X-Ray Free Electron Emission**

S. Carbajo, *F.-J. Decker, Z. Huang, J. Krzywiński, R.A. Lemons, W. Liu, A.A. Lutman, G. Marcus, T.J. Maxwell, S.P. Moeller, D.F. Ratner, J. Tang, S. Vetter (SLAC)*

We present theoretical studies and experimental results on the role of spatial shaping of diverse laser modes in free electron lasers (FEL) resulting in better suppression of the e-beam microbunching instability and its impact on self-seeded X-ray FEL performance as well as other advanced modes of FEL operation. Experimentally, we employ LCLS to demonstrate that a Laguerre-Gaussian 01 (LG01) transverse mode of the laser heater (LH) induces a Gaussian energy distribution of the e-beam with controlled spread. Directly from the resulting heated e-beam energy distribution, we show evidence of improvement on microbunching instability suppression compared to routine operations. We have also studied the impact of the LG01 LH on soft X-ray self seeding performance and its monochromaticity or spectral brightness, and obtained highly monochromatic FEL seeded spectra. These results will fuel the next generation of engineered laser heater designs for existing and future augmented brightness linacs and X-ray FELs.

THP035 **Beam Shaping for High-Repetition-Rate X-Ray FELs**

Y. Ding, *K.L.F. Bane, Y.M. Nosochkov (SLAC)*

Beam shaping at the normal-conducting accelerator-based FELs such as LCLS plays an important role for improving the lasing performance and supporting special operating mode like self-seeding scheme. This includes horn-collimation method, dechirper manipulation and others. Applying the beam shaping concept to high-repetition-rate FELs driven by a superconducting linac, beam invasive method is not preferred due to high power concerns. We recently studied a few options at the LCLS2 by manipulating the beam chirp before compression with corrugated devices, and by modifying the higher order optics terms in a chicane with octupoles. We will discuss these beam shaping results.

THP036 **Microbunch Rotation for Hard X-Ray Beam Multiplexing**

R.A. Margraf, *Z. Huang, J.P. MacArthur, G. Marcus (SLAC) X.J. Deng (TUB) Z. Huang, J.P. MacArthur,* ***R.A. Margraf*** *(Stanford University)*

Electron bunches in an undulator develop periodic density fluctuations, or microbunches, which enable the exponential gain of X-ray power in a SASE FEL. Many FEL applications could benefit from the ability to preserve microbunching when a bunch experiences a dipole kick. For example, X-ray beam multiplexing can be achieved if, prior to saturation, electron bunches are kicked into separate beamlines and allowed to lase in a final undulator. The microbunches developed in upstream undulators, if properly rotated, will lase off axis, producing radiation at an angle offset from the initial beam axis. Microbunch rotation was demonstrated experimentally with soft X-rays by *MacArthur et al.* and succeeded in multiplexing LCLS into three X-ray beams. Additional 2018 data demonstrated multiplexing of hard X-rays. Here we describe efforts to reproduce these hard X-ray multiplexing experiments using Genesis simulations. We also apply the microbunch rotation to out-coupling from a Regenerative-Amplifier Free-Electron Laser (RAFEL), the concept for which is further described in work presented by G. Marcus at this conference.

THP037 **A Novel One-Dimensional Model for CSR Wakefields**

G. Stupakov *(SLAC)*

The existing 1D models of the coherent synchrotron radiation (CSR) wakefield in free space assume that the longitudinal bunch distribution remains constant when the beam propagates through a magnetic lattice. In this paper, we derive a formula for a 1D CSR wake that takes into account variation of the bunch length along the orbit. The formula is valid for arbitrary curvilinear beam trajectory. We analyze the validity of the 1D model in a typical implementation of an FEL bunch compressor.

THP039 **Studying Ultrafast Dynamics at Free Electron Laser Sources Enabled by Hard X-Ray Split-and-Delay Line**

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Probing matter on time scales ranging from femtoseconds to nanoseconds is one of the key topics at X-ray Free Electron Laser sources. Studying dynamics with X-ray Photon Correlation Spectroscopy or an X-ray pump/X-ray probe technique at time scales shorter than 222 ns is experimentally not feasible due to the intrinsic time structure of the source. Here, we report an important step towards probing ultrafast dynamics at XFEL sources by using a prototype perfect crystal-based split-and-delay system, capable of splitting individual X-ray pulses and introducing femto- to nanosecond time delays. We show the development of split-and-delay device, demonstrate its femtosecond-precision time delay capability and results of the first ultrafast XPCS experiments at LCLS where split FEL pulses were used to measure ultrafast Brownian motions of nanoparticles suspended in a liquid on nanosecond-picosecond timescales. This capability promises to elucidate the underlying dynamics of a wide variety of systems and will enable the discovery of new physical processes therein. We also present development of the future compact split-and-delay-line device.

THP040 **Femtosecond X-Ray Absorption Spectroscopy at the SCS Instrument of European XFEL**

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X-ray absorption spectroscopy (XAS) is one of the experimental techniques offered at the Spectroscopy and Coherent Scattering (SCS) instrument that is now operational at the soft X-ray branch SASE3 of European XFEL.

The beamline photon energy range (400-3000 eV) covers the important L absorption edges of transition metals, M edges of rare-earths, K edges of light elements such as oxygen. The pulse structure of SASE3 allows measuring the XAS with X-ray pulse durations down to few fs. The transmission XAS measurements are realized by using the X-ray Gas Monitor (XGM) and the Transmission Intensity Monitor (TIM) to record the incident and transmitted intensity, respectively. XGM allows non-invasive measurement of pulse energy using photoionization in gases. TIM is the intensity detector based on the X-ray fluorescence from the solid state scintillator (CVD diamond) measured with the micro-channel plate (MCP) detectors mounted under different angles from the normal emission. Both devices detect the X-rays in a wide photon energy range and provide the data output with a single pulse resolution. The time required for obtaining the good data statistics is of the order of few minutes.

`THP041` **Interaction of Powerful Electro-Magnetic Fields With Bragg Reflectors**

***I. Bahns**, W. Hillert, P. Rauer, J. Roßbach (University of Hamburg, Institut für Experimentalphysik) H. Sinn (EuXFEL)*

The interaction of an X-ray free electron laser (XFEL) with a Bragg reflector can cause a change of the lattice constant which has a direct influence on the stability of the reflection conditions and can also excite modes of vibration. The dynamical thermoelastic effects of the photon-matter-interaction are simulated with a finite-element-method (FEM) using the assumptions of continuums mechanics. To compare the simulation results with measured signals an in-house experimental pump-probe setup has been built up which uses three different methods, that all use ultrafast photodiodes resulting in a temporal resolution <200 ps. An interferometer is used to measure displacement and a knife edge method to detect angular changes due to the propagation of ultrasonic waves. A thermoreflectance method is used to investigate thermal properties. A pulsed UV laser (pump) is used to deposit an energy amount of about 1 µJ. The photon-matter interaction takes place in a vacuum chamber. With a cryogenic cooler the temperature can be adjusted down to 50 K, which gives the possibility to change the material properties in a way that it optimizes the stability conditions for a Bragg reflector.

`THP042` **Implementation of a Laser Compton Scattered Gamma Source in Geant4**

***R. Hajima** (QST)*

Generation of gamma photons from Compton scattering is one of the promising applications of free-electron lasers as proven by HIGS at Duke University. Monte Carlo simulations are essential for optimizing an experimental layout in a laser Compton scattered gamma source facility as well as analyzing results of gamma-ray experiments. Geant4 is a software toolkit for Monte Carlo simulations and developed continuously by world-wide collaboration. We implemented a laser Compton scattered gamma source in Geant4. The implemented model provides a primary particle source to generate gamma photons with arbitrary electron and laser beam parameters at laser Compton scattering. In this paper, benchmarking of the implemented model with other simulation codes and experimental results are presented.

`THP043` **Imaging Molecular Photodissociation Dynamics at the Dalian Coherent Light Source (DCLS)**

***Z. Chen**, Y. Chang, D.X. Dai, H.L. Ding, Z.G. He, Q.M. Li, Z.B. Li, Z.J. Luo, L. Shi, K. Tao, Y.H. Tian, G.R. Wu, J.Y. Yang, X.M. Yang, Y. Yu, K.J. Yuan, W.Q. Zhang, Z.G. Zhang, J.M. Zhou (DICP) M.N.R. Ashfold (University of Bristol)*

Time-Sliced Ion Velocity imaging was implemented at the free electron laser in Dalian to investigate molecular photodissociation dynamics. High quality energy and angular distributions were recorded for small molecules (O2, H_2O and SO2). This proof-of-principle experiment illustrates the potential for using Time-Sliced Ion Velocity Imaging in order to study photodissociation processes.

`THP044` **The Simulation Study for Single and Multi Turn ERL Based EUV FEL**

***K.M. Nam** (POSTECH) Y.W. Parc (PAL)*

Photolithography technology is the core part of the semiconductor manufacturing process. It has required light having stronger power for higher throughput. ERL based EUV FEL is emerging as a next generation EUV source which can produce the light over 10 kW. In this study, first, EUV-FEL design, which is based on single turn, is represented. It accelerates 40 pC electron beam to 600 MeV and produces EUV, whose wavelength and power are 13.5 nm and 37 kW. Second, multiturn based design is represented. It improved compactness to make it more suitable for industrial use. As a result, the electron beam was able to obtain the kinetic energy and circulate, and the size was reduced to about half without reducing the power greatly. This study is expected to increase the practical industrialization potential of ERL-based photolithography.

`THP045` **High Power FELs for Orbital Debris Removal**

***G. Neil** (Double Helix Art LLC) G.H. Biallas (JLab) D. Douglas (Douglas Consulting) H. Freund (University of New Mexico) D.O. Neil (Private Address) R.R. Whitney (BNNT, LLC)*

Recent advances in the technologies of high-power Free Electron Lasers (FELs), e.g., injectors with high average current at low emittance, approaches for improved energy extraction through wiggler tapering with strong focusing, mitigation of CSR brightness dilution, and high current energy recovery now render very high power FEL operation feasible. Such FELs would utilize maturing designs for 4K superconducting linear accelerators. A ground-based device is capable of eliminating orbital debris in low Earth orbits. Such debris has become a major issue in the operation of satellites and manned space missions. Effective methods exist for targeting an estimated 500,000 low Earth orbit objects in <10 cm characteristic size range giving estimates of beam director sizes, system operating range, dwell times, optical power and desired wavelengths leading to the technical parameters for the FEL and accelerator. Such a system could significantly reduce the debris count by operating semi-continuously over periods of several years.

THP046 **Free Electron Nano-Laser in Graphene Nanostructures**

***H.K. Avetissian**, G.F. Mkrtchian (YSU)*

Induced Cherenkov radiation has been among the first FEL schemes with the advent of the FEL concept. Although this mechanism has many advantages for FEL from the point of view transformation of kinetic energy of particle beam into EM radiation. Nevertheless, the necessity of ultrarelativistic electron beam of high density and dielectric medium restricts the operation of Cherenkov FEL due to the multiple scattering and ionization losses of particles in the atomic-molecular matter. Hence, it is important to find out physical circumstances when Cherenkov FEL will operate practically. In modern nano-electronics-photonics it is of great interest nanoFEL. As a possible version of the latter we propose a new scheme of nanoFEL based on the quantum 2D Cherenkov effect in graphene nanostructures via plasmon-polariton modes, overcoming by that requirements on ultrarelativistic electron beam and macroscopic medium.

THP047 **Laser-Driven Compact Free Electron Laser Development at ELI-Beamlines**

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The ELI-Beamlines Centre, located near Prague (Czech Republic) is an international user facility for fundamental and applied research. Using the optical parametric chirped-pulse amplification (OPCPA) technique, the ELI-Beamlines laser system will provide the laser pulse energy up to 10 Joules with the repetition rate up to 25 Hz. Combination of new laser development with constant improvement of the LWFA electron beam parameters has great potential in future development of the compact high repetition rate Free Electron Laser. The LWFA-driven FEL project, called "LUIS", is currently under preparation at ELI-Beamlines in collaboration with the University of Hamburg. The goal of the project is the improvement of the electron beam parameters in order to demonstrate the amplification and saturation of the SASE-FEL photon power in a single unit of the FEL undulator. A successful realization of the LUIS project will open a way to a next generation of laser-driven X-FELs. An overview of the LUIS project including design features and a description of all instrumentations used to characterize the laser, plasma, electron beam, photon generation will be presented in frame of this report.

THP048 **Progress Towards Laser Plasma Electron Based Free Electron Laser on COXINEL**

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Laser plasma acceleration (LPA) with up to several GeV beam in very short distance appears very promising. The Free Electron Laser (FEL), though very challenging, can be viewed as a qualifying application of these new emerging LPAs. The energy spread and divergence, larger than from conventional accelerators used for FEL, have to be manipulated to fulfil the FEL requirements. On the test experiment COXINEL (ERC340015), the beam is controlled in a manipulation line, using permanent magnet quadrupoles of variable strength for emittance handing and a decompression chicane equipped with a slit for the energy selection, enabling FEL amplification for baseline reference parameters. The electron position and dispersion are independently adjusted. The measured spontaneous emission radiated by a 2 m long 18 mm period cryo-ready undulator exhibits the typical undulator spatio-spectral pattern, in agreement with the modelling of the electron beam travelling along the line and of the afferent photon generation. The wavelength is easily tuned with undulator gap variation. A wavelength stability of 2.6% is achieved. The undulator linewidth can be controlled.

THP049 **Beam Based THz Generation With Waveguides**

***F. Lemery**, M. Dohlus, K. Flöttmann (DESY) M. Ivanyan (CANDLE)*

THz radiation has a broad range of applications for e.g. pump probe spectroscopy, imaging, and accelerator applications. In this paper we discuss beam-based THz generation in various types of waveguides. We present a case study oriented toward the European XFEL and discuss a range of available high-power THz options which could accommodate users.

THP050 **Possibility of Adding a Slotted Foil at the European XFEL**

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A slotted foil can be used to generate femtosecond and sub-femtosecond X-ray pulses at the free electron facilities, and two color femtosecond pulses can be generated by inserting a double slot foil at the bunch compressor location to spoil the emittance of the electron bunch. This advanced scheme has been demonstrated experimentally at the LCLS. At the European XFEL, however, radiation losses caused by a slotted foil is a major concern for the downstream cryomodules. In this paper, we present the study of possible radiation doses that can be generated by the insertion of a slotted foil using BDSIM tracking and loss simulations.

THP051 **Generating Trains of Attosecond Pulses at Pohang Free-Electron Laser**

***S. Serkez**, G. Geloni (EuXFEL) M.H. Cho, H.-S. Kang, G. Kim, J.H. Ko, C.-K. Min, I.H. Nam, C.H. Shim (PAL) F.-J. Decker (SLAC) J.H. Ko, C.H. Shim (POSTECH) Yu. Shvyd'ko (ANL)*

Recently, a Hard X-ray Self-Seeding setup was commissioned at PAL XFEL. Its main purpose is to increase the temporal coherence of FEL radiation in an active way. We report another application of this setup to generate trains of short sub-femtosecond pulses with linked phases. We discuss preliminary results of both experiment and corresponding simulations as well as indirect diagnostics of the radiation properties.

THP052 **Development of an Artificial Intelligence System for the Design of an Optical Mode Converter**
***M.G. Gerasimov**, E. Dyunin, A. Friedman (Ariel University)*
Terahertz irradiation and sensing is being applied lately to a wide range of fields outside the traditional niches of space science, molecular line spectroscopy, and plasma diagnostics. This research proposal presents a new technique for converting optical and quasi-optical modes by using Artificial Intelligence. The final purpose is to develop tool for designing system of specialized (printed) mirrors. The motivation is that traditional methods cannot supply a good, or even satisfactory solutions in the terahertz range, due to a much higher diffraction than what is know in the optical regime (infra-red to ultra-violet).

THP054 **Nanosecond Pulse Enhancement in a Narrow Linewidth Cavity for Steady-State Microbunching**
***Q.H. Zhou** (Southwest University of Science and Technology)*
In steady-state microbunching (SSMB), nanosecond laser pulse with megawatt average power is required. We build up a theoretic model to enhance such pulse in a narrow linewidth (e.g. kHz level) cavity for this demand, which shows that a mode-locked mechanism in frequency domain should be considered. Simulations indicate that such pulse can be enhanced sufficiently under this condition. And we also propose some experimental schematics to realize it.

THP055 **A Storage Ring Design for Steady-State Microbunching to Generate Coherent EUV Light Source**
***Z. Pan** (TUB)*
In order to generate EUV light source with extremely high power, we propose a concept that storage a very short electron beam below 100 nm in the ring, and insert a strong focusing part to compress the beam and get a ~3 nm electron beam, passing the undulator and radiating coherently. We have optimized the first order momentum compaction factor, second order momentum compaction factor, local momentum compaction factor (partial alpha) and dynamic apertures for this lattice to achieve the stable storage for the 100 nm electron beam. The tracking results show the equilibrium bunch length of the electron is about 40 nm and no particles lost after 4.5 damping time while only single-particle effect considered.

THP056 **Tunable Terahertz Radiation Excited by Electron Beam in Sub-Wavelength Hole Array With Dielectric**
***W. Liu** (USTC/NSRL)*
We analyze the electron radiation in terahertz region utilizing sub-wavelength hole array (SHA) in a conducting plane. The model can be viewed as a periodic system. Because the spatial period we choose is comparable to the radiation wavelength, the field theory is used to develop the dispersion characteristics. When dielectric is filled in SHA, we get new dispersion characteristics which are corresponding to the permittivity of dielectric. Furthermore, the velocity of the free electron beam can be set the same as the phase velocity of the radiation, which makes it possible for the radiation to interact with the electron effectively. Considering its high feasibility, it may be a novel way for amplifiers and particle accelerators.

29 Aug – Thu

THP057 **Critical Issues on Laser Wakefield Electron Accelerators Using Solid Targets for Compact Light Sources**
***S.Y. Shin**, S.J. Hahn (Chung-Ang University) J. Kim (KERI) K. Lee (KAERI) S.H. Park (KUS)*
The laser wakefield acceleration (LWFA) using a laser ablation plasma from a solid target has been suggested to operate in a higher vacuum condition and with higher repetition rate than using a gas target. The laser intensity of greater than 10^{19} W/cm^2 generally required for the LWFA is strong enough to ionize the partially-ionized ions in laser ablation plasma. The ionization effect on LWFA using solid targets was investigated via the PIC (Particle-In-Cell) simulation using a 2D3V EPOCH code to find the optimal condition for high quality of electron beam. In this paper, we present the ionization effects on LWFA mechanism depending on the intensity and focal spot size of main laser as well as the density of initial plasma, i.e., laser ablation plasma. The effect of sequential ionization processes on LWFA is also reported using different target materials, having different ion appearance intensities of L-shell electrons, such as, copper and titanium.

THP058 **Coherent and Femtosecond Operation Mode for New Advanced Synchrotron Light Source in Korea**
***Y. Kim** (KAERI) I.G. Jeong (University of Science and Technology of Korea (UST)) I.G. Jeong, J.Y. Lee (Korea Atomic Energy Research Institute (KAERI))*
Recently, the demand of a new advanced synchrotron light source in Korea is rapidly growing. Six local governments in Korea would like to host the new synchrotron light source facility in their own province. The new advanced synchrotron light source will have a 6 GeV superconducting linac for the CW mode injection, a 1.5 GeV synchrotron for the EUV and soft X-ray users, and a 6 GeV synchrotron, which is based on the diffraction limited storage ring (DLSR) concept. The 6 GeV synchrotron will have two 60 m long undulator beamlines to deliver coherent and femtosecond long X-rays. In this paper, we report design concepts and the coherent and femtosecond long X-ray operation mode of those 60 m long undulator beamlines.

THP059 **Optimization of Isolated Terawatt Attosecond X-Ray FEL Pulse Generation**
***C.H. Shim**, D.E. Kim, <u>I.H. Nam</u>, Y.W. Parc (PAL)*
Micro-bunching instability (MBI) is considered as a critical obstacle for the realization of the isolated terawatt attosecond XFEL. To make high a peak current, the distribution of the electron beam in the phase space should be uniform. The micro-bunching instability will twist the distribution which results in very low peak current value. The effect by MBI has been investigated and a proposal is provided to overcome the obstacle. This will pave a way to the realization of a terawatt level, isolated attosecond pulse at X-ray region.

THP060 **Development of RF-Undulators and Powering Sources for Compact Efficient Compton FEL-Scattrons**
***A.V. Savilov**, E.D. Abubakirov, N.S. Ginzburg, N.Yu. Peskov, A.A. Vikharev, V.Yu. Zaslavsky (IAP/RAS) S.V. Kuzikov (Euclid Beamlabs LLC)*
Conception of Compton-type FELs operating up to X-ray band is under development currently at IAP RAS

(N.Novgorod). This concept is aimed at reducing energy of a driving relativistic electron beam and thereby increasing efficiency of the electron-wave interaction in FEL, as well as achieving relative compactness of the generator. The basis of this concept is RF-undulators of a new type - the so-called 'flying' undulators. Results of current research of these RF-undulators, their simulations and 'cold' tests in the Ka-band are presented. For powering RF-undulators spatially-extended narrow-band Cerenkov masers are developed in the specified frequency range. In order to achieve the required sub-gigawatt power level of the pumping wave in a strongly oversized oscillator, we exploit the original idea of using two-dimensional distributed feedback implemented in the 2D doubly-periodical slow-wave structures. The design parameters of Ka-band surface-wave oscillator intended for powering RF-undulators, results of its simulation and initial experimental studies are discussed.

THP061 **Bayesian Optimisation for Fast and Safe Parameter Tuning of SwissFEL**

***J. Kirschner**, A. Krause, M. Mojmir, M. Nonnenmacher (ETH) , N. Hiller, R. Ischebeck (PSI)*

Parameter tuning is a notoriously time-consuming task in accelerator facilities. As tool for global optimization with noisy evaluations, Bayesian optimization was recently shown to outperform alternative methods. By learning a model of the underlying function using all available data, the next evaluation can be chosen carefully to find the optimum with as few steps as possible and without violating any safety constraints. However, the per-step computation time increases significantly with the number of parameters and the generality of the approach can lead to slow convergence on functions that are easier to optimize. To overcome these limitations, we divide the global problem into sequential subproblems that can be solved efficiently using safe Bayesian optimization. This allows us to trade off local and global convergence and to adapt to additional structure in the objective function. Further, we provide slice-plots of the function as user feedback during the optimization. We showcase how we use our algorithm to tune up the FEL output of SwissFEL with up to 40 parameters simultaneously, and reach convergence within reasonable tuning times in the order of 30 minutes (< 2000 steps).

THP062 **Analysis Cavity Coating Thermal Noise in FEL**

***M. Ying** (NTHU)*

A storage-ring based steady-state micro-bunching (SSMB) configuration is a bright prospect approach providing EUV source over kilowatts level average power meeting enormous manufacturing requirements for EUV lithography (Extreme Ultra Violate lithography). Restricted by the SSMB mechanism, this system is very sensitive to noise disturbance. In this letter, we focus on discriminate Brownian thermal noise effect in SSMB enhancement cavity design. We will introduce the interaction between light field fluctuation with the electron beam, and explore the range of tolerance to justify the Brownian thermal noise influence in SSMB cavity. Through surface Brownian thermal noise cause tiny deformation on the coating mirror, thus impact the reflection optical field phase and amplitude overlap individual, eventually, simulate the superposition optical field interacts with the electron beam for modulating, we will evaluate the effect of thermal noise from three different aspects. Through these methods, we can analysis thermal noise effect in the sophisticated accelerator system.

THP063 **ColdLight: From Laser-Cooled Atoms to Coherent Soft X-Rays**

***O.J. Luiten**, J.G.H. Franssen, P.H.A. Mutsaers, D.F.J. Nijhof, B.H. Schaap, T.C.H. de Raadt (TUE)*

At Eindhoven University of Technology a pulsed, ultracold electron source (UCES) is being developed, based on femtosecond, near-threshold photoionization of a laser-cooled and trapped atomic gas. Source temperatures of ~10 K are routinely achieved, resulting in picosecond bunches with ~1nm rad normalized emittance. In the ColdLight project the UCES will be used to drive a fully coherent Inverse Compton Scattering (ICS) soft X-ray source. The ultra-low emittance enables generation of fully spatially coherent soft X-ray pulses. The two-step photoionization scheme allows intricate structuring of the electron bunch, in particular pre-bunching at optical wavelengths. Combining the pre-bunching with standard RF bunch compression results in micro-bunching at soft X-ray wavelengths and thus full temporal coherence as well. It is intriguing to note that the soft X-ray emission by such bunches should be enhanced by super-radiance, suggesting the possibility of realizing a compact and easily tunable soft X-ray Free Electron Laser. Detailed particle tracking simulations and commissioning of a compact, turn-key, grating-MOT based UCES will be presented.

THP064 **Smart*Light: A Tunable Inverse Compton Scattering (ICS) X-Ray Source for Imaging and Analysis**

***O.J. Luiten**, P.H.A. Mutsaers, X.F.D. Stragier (TUE) T.G. Lucas (ARCNL)*

A tunable, tabletop, Inverse Compton Scattering (ICS) hard X-ray source is being designed and built at the Eindhoven University of Technology. This compact X-ray source will bridge the gap between conventional lab sources and synchrotrons: The X-ray photon energy will be generated between 1 and 100 keV with a brilliance typically a few orders of magnitude above the best available lab sources. Smart*Light will find applications in material science, cultural heritage and medical imaging. In the ICS process photons from a laser pulse bounce off a relativistic electron bunch, turning them into X-ray photons through the relativistic Doppler effect. Smart*Light will use a 100 kV DC photogun as electron source and compact X-band linear accelerator technology developed by the CLIC program from CERN to accelerate the electrons further to an energy of maximal 50 MeV. A 100 mJ, 500 nm, 1 ps laser pulse will be focused to a 5 micrometer spot and interact with the electron pulse that will be also focused to a spot of about 5 micrometer resulting in X-ray photons with an energy up to 100 keV, an emission angle of < 0.8 mrad, and a brilliance up to $9*10^{14}$ photons/s/mm2/mrad2/0.1% bw.

THP065 **Multi-Objective FEL Design Optimisation Using Genetic Algorithms**

***D.J. Dunning**, H.M. Castaneda Cortes, J.K. Jones, N. Thompson (STFC/DL/ASTeC) J.K. Jones, N. Thompson (Cockcroft Institute)*

Simulation studies were carried out to optimise the performance of various FEL designs, with examples including longitudinal current profile shaping for a seeded FEL, and selection of the chicane delays for the High-

Brightness SASE technique. In these examples multi-objective genetic algorithms were applied to a single section of the overall facility simulation, i.e. the undulator, as is the common approach. Further studies are also reported in which a full start-to-end simulation chain was optimised, with the aim of delivering a more holistic facility design optimisation.

THP066 **XARA: X-Band Accelerator for Research and Applications**

D.J. Dunning, *L.S. Cowie, J.K. Jones (STFC/DL/ASTeC) L.S. Cowie, J.K. Jones (Cockcroft Institute) L.S. Cowie (Cockcroft Institute, Lancaster University)*

XARA (X-band Accelerator for Research and Applications) is a proposal for a compact ~1 GeV accelerator to produce attosecond light pulses in the EUV to soft X-ray region. It is under consideration as a potential future upgrade to the CLARA facility at Daresbury Laboratory, utilising high-performance X-band RF technology to increase the electron beam energy from 250 MeV. Emerging techniques for generating single-cycle undulator light would give access to attosecond timescales, enabling studies of ultra-fast dynamics, while also being very compact. XARA would also enhance the existing capabilities for accelerator science R&D by incorporating X-band development and increasing the electron beam energy for novel acceleration studies.

THP067 **Vector Light Beams from Relativistic Electrons**

J.F. Morgan, *B.W.J. McNeil, A.M. Yao (USTRAT/SUPA) E. Hemsing (SLAC) B.W.J. McNeil (Cockcroft Institute)*

The vector superposition of orthogonally polarised modes carrying orbital angular momentum can create light beams which have spatially inhomogeneous polarisation states. However, these beams can be limited in intensity and wavelength by the optics used to create them. This work explores generation techniques which change the phase structure and polarisation of the light through manipulation of a radiating, highly relativistic electron beam and do not rely on external optics. Vector beams will be investigated using the free electron laser simulation code Puffin.

THP068 **LCLS-II Extruded Aluminum Undulator Vacuum Chambers — New Approaches to an Improved Aperture Surface Finish**

G.E. Wiemerslage, *P.K. Den Hartog, J. Qian, M. White (ANL)*

The Linac Coherent Light Source, (LCLS) the world's first x-ray free electron laser (FEL) became operational in 2009. The Advanced Photon Source contributed to the original project by designing and building the undulator line. Two slightly different variations of these chambers were required for LCLS-II: one for a soft X-ray (SXR) undulator line, and one for a hard X-ray (HXR) undulator line. Because of the extremely short electron bunch length, a key physics requirement was to achieve the best possible surface finish within the chamber aperture. Improvements to our earlier fabrication methods allowed us to meet the critical surface roughness finish defined by RF impedance requirements. We were able to improve the surface finish from an average of 812 nm rms to 238 nm rms. The average longitudinal surface roughness slope of all chambers was to be less than 20 mrad. We achieved an average longitudinal surface roughness slope of 8.5 mrad with no chamber exceeding 20 mrad. In the end, sixty-four undulator vacuum chambers and alignment systems were delivered to SLAC for the LCLS-II Upgrade project. Here we will report on the process improvements for the fabrication of these chambers.

THP069 **Observations on Microbunching of Electrons in Laser-Driven Plasma Accelerators and Free-Electron Lasers**

A.H. Lumpkin *(Fermilab) M. Downer, M. LaBerge (The University of Texas at Austin) D.W. Rule (Private Address)*

The periodic longitudinal density modulation of relativistic electrons at the resonant wavelength (microbunching) is a fundamental aspect of free-electron lasers (FELs). In one case, microbunching fractions reached 20% at saturation of a self-amplified spontaneous emission (SASE) FEL resulting in gains of 1 million at 530 nm. In that experiment the z-dependent gain of coherent optical transition radiation (COTR) was also measured. In laser-driven plasma accelerators (LPAs), microbunching at visible wavelengths has also been recently reported as evidenced by significant COTR enhancements measured in near-field and far-field images on a single shot for the first time. An analytical model for COTR interferometry (COTRI) addresses both cases. In the FEL, one identified microbunched transverse cores of 25-100 microns while in the LPA the reported transverse sizes at the exit of the LPA were a few microns. In the latter case, signal enhancements of nearly 100,000 and extensive fringes out to 30 mrad in angle space were recorded. The broadband microbunching observed in the LPA case could act as a seed for a SASE FEL experiment with tunability in principle over the visible regime.

THP070 **Development of Advanced Model-Independent Tuning Methods for Maximizing Free Electron Laser Pulse Energy at the EuXFEL at DESY**

A. Scheinker *(LANL) B. Beutner, W. Decking, R. Kammering, H. Schlarb, M. Scholz, I. Zagorodnov (DESY) D.K. Bohler (SLAC) S. Tomin (EuXFEL)*

The output power of a free electron laser (FEL) has extremely high variance even when all FEL parameter set points are held constant because of the stochastic nature of the self-amplified spontaneous emission process, uncertainty and time-variation of thousands of coupled parameters, and uncertainty and time variation of the electron distribution coming off of the photo cathode and entering the accelerator. In this work, we present the development and application of automatic, model-independent feedback for the maximization of average pulse energy of the light produced by FELs carried out at the European X-ray free electron laser at DESY. We present experimental results in applying these techniques at both the EuXFEL at the LCLS on RF systems for automatically adjusting the longitudinal phase space of the beam, for adjusting the phase shifters in undulators, and for adjusting steering magnets between undulator sections to maximize FEL output power. We show that we can tune up to 10^5 components simultaneously based only on noisy average bunch energy measurements. We also present preliminary work on advanced machine learning techniques taking place at the EuXFEL at DESY.

THP071 **High Power and Brightness Double Bunch LCLS-II**

***F.-J. Decker**, Y. Ding, C. Emma, A. Halavanau, Z. Huang, J. Krzywiński, A.A. Lutman, G. Marcus, A. Marinelli, A. Ratti, D. Zhu (SLAC) C. Pellegrini (UCLA)*

We show that we can generate near TW, 15 fs duration X-ray pulses in the 4 to 8 keV photon energy range using the LCLS-II copper linac, two bunches and a 4-crystal monochromator/delay line. The first bunch generates a strong seeding X-ray signal, and the second bunch, initially propagating off-axis, interacts with the seed in a tapered amplifier undulator. We show that increasing the seed power above 100 MW increases the output power and provides a near transform limited spectrum. We investigate the 4-crystal monochromator, acting also as an X-ray delay system. We consider applications to high intensity, high-field physics experiments, including imaging , non linear atomic physics and QED above the critical Schwinger field.

THP072 **Phase-Stable Self-Modulation of an Electron-Beam in a Magnetic Wiggler**

***J.P. MacArthur** (SLAC)*

Electron-beams with a sinusoidal energy modulation have the potential to emit sub-femtosecond X-ray pulses in a free-electron laser. The energy modulation can be generated by overlapping a powerful infrared laser with an electron-beam in a magnetic wiggler. Here we report on a new infrared source for this modulation, coherent radiation from the electron-beam itself. In this self-modulation process, the current spike on the tail of the electron-beam radiates coherently at the resonant wavelength of the wiggler, producing a six-period carrier-envelope-phase (CEP) stable infrared field with gigawatt power. This field creates a few MeV, phase-stable modulation in the electron-beam core. The modulated electron-beam is immediately useful for generating sub-femtosecond X-ray pulses at any machine repetition rate, and the CEP-stable infrared field may find application as an experimental pump or timing diagnostic.

THP073 **High Efficiency and High Gain Amplification at 266 nm Wavelength**

***P. Musumeci**, Y. Park, N.S. Sudar (UCLA) R.B. Agustsson, T.J. Campese, I.I. Gadjev, A.Y. Murokh (RadiaBeam) D.L. Bruhwiler, C.C. Hall, S.D. Webb (RadiaSoft LLC) Y. Sun, A. Zholents (ANL)*

Tapering Enhanced Stimulated Superradiant Amplification (TESSA) allows to increase the efficiency of Free Electron Laser (FEL) based radiation generation from ~0.1% to 10% by using intense seed laser pulses, strongly tapered undulators and prebunched electron beams. Initial results validating this method have already been obtained at 10 µm wavelength at Brookhaven National Laboratory. We will present the design of an experiment to demonstrate the TESSA scheme at high gain and shorter wavelength (266 nm) using the APS injector linac at Argonne National Labor-atory (ANL) to obtain conversion efficiency of up to 10%. Undulator and focusing lattice design, as well as beam dynamics and diagnostics for this experiment will be discussed. An extension of the experiment to include the possibility of multi-bunch linac operation and an optical cavity around the undulator to operate in the TESSO regime will also be presented.

THP074 **FLASH: The Pioneering XUV and Soft X-Ray FEL User Facility**

***K. Honkavaara**, S. Schreiber (DESY)*

FLASH, the free-electron laser (FEL) at DESY (Hamburg) started user operation in summer 2005. It delivers high peak and average brilliance XUV and soft X-ray FEL radiation to photon experiments. Nowadays, FLASH has a 1.25 GeV superconducting linac, and two undulator beamlines, which are operated simultaneously. This paper provides an overview of its evolution from a test facility for superconducting accelerator technology to a full-scale FEL user facility.

THP076 **High Bunch Charge Operation of the TELBE Super-Radiant THz Source With the ELBE SRF Gun**

***U. Lehnert**, A. Arnold, M. Chen, J.-C. Deinert, P.E. Evtushenko, B.W. Green, J.M. Klopf, S. Kovalev, S. Ma, P. Michel, J. Schaber, J. Teichert, R. Xiang (HZDR)*

The ELBE Radiation Source operates several secondary radiation sources driven by a CW superconducting RF (SRF) linac, including two THz/IR FELs (FELBE), and in 2016, regular operation of TELBE, a super-radiant 8-pole THz undulator source and a coherent diffraction radiation (CDR) source, began. The tunable undulator source (0.1 - 1.5 THz) generates multicycle CEP stable transform-limited pulses with ~20% bandwidth, while the broadband CDR source generates single cycle pulses with 100% bandwidth. Recent improvements of the ELBE SRF electron gun have enabled delivery of high bunch charge (up to 250 pC) at a high repetition rate (100 kHz CW) to the TELBE sources. This achieved the highest pulse energy to date from the TELBE undulator (10 µJ/pulse) at 0.3 THz, which is an average power of 1 W. The photon parameters, particularly of the undulator source are ideal for studying high-field driven nonlinear processes in low-dimensional materials and quantum systems. Details regarding these recent performance milestones for the TELBE undulator source with the ELBE SRF gun will be reported.

THP077 **General Design and Status of the FEL Facility in Isreal**

***A. Friedman**, K. Cheverdine, E. Dyunin, Yu. Lurie, A.N. Nause (Ariel University) A. Gover (University of Tel-Aviv, Faculty of Engineering)*

The Schlesinger Accelerator Center in Ariel University is in the process of constructing a Tera Hertz FEL. The device is based planned to operate on the principle of superradiance. It is designed to operate in two modes (1) A single pulse of up to 150 fsec in length and (2) a bunched beam at the frequency of the desired radiation. It is designed to generate radiation of 1 - 3.5 THz. We report the status of the FEL facility. The photocathode 6.5 MeV gun has been launched and we will report the diagnostics results of the electron beam.

THP078 **Status of the CompactLight Design Study**

***G. D'Auria** (Elettra-Sincrotrone Trieste S.C.p.A.)*

CompactLight (XLS) is an International Collaboration of 24 partners and 5 third parties, funded by the European Union through the Horizon 2020 Research and Innovation Programme. The main goal of the project, which started in January 2018 with a duration of 36 months, is the design of an hard X-ray FEL facility beyond today's state of the art, using the latest concepts for bright electron photo-injectors, high-gradient accelerating structures, and innovative short-period undulators. The specifications of the facility and the parameters of the future FEL are driven by the demands of potential users and the associated science cases. In this paper we will give an overview on the ongoing activities and the major results achieved until now.

THP079 **Status and Perspectives of the FERMI FEL Facility (2019)**

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FERMI is the seeded Free Electron Laser (FEL) user facility at the Elettra laboratory in Trieste, operating in the VUV to EUV and soft X-rays spectral range; the radiation produced by the seeded FEL is characterized by wavelength stability, low temporal jitter and longitudinal coherence in the range 100-4 nm. During 2018 a dedicated experiment has shown the potential of the Echo Enabled Harmonic Generation (EEHG) scheme to cover most of this spectral range with a single stage cascade. Such a scheme, combined to an increment of the beam energy and of the accelerator performances, could extend the FERMI operating range toward the oxygen k-edge. With this perspective, we present the development plans under consideration for the next 3 to 5 years. These include an upgrade of the linac and of the existing FEL lines, consisting in the conversion of FEL-1 first, and FEL-2 successively, into EEHG seeded FELs.

THP080 **The Status of Dalian Coherent Light Source and Future Plan**

W.Q. Zhang, *X.M. Yang (DICP) D. Wang (SARI-CAS) Z.T. Zhao (SSRF)*

A Free Electron Laser with high brightness, ultrafast laser pulses in the vacuum ultraviolet (VUV) wavelength region is an ideal light source for excitation of valence electrons and ionization of molecular systems with very high efficiency. It is quite helpful for studies of important dynamic processes in physical, chemical and biological systems. Dalian Coherent Light Source (DCLS), as the unique VUV light source from 50-150 nm in the world, have delivered bright optical beam in picoseconds or 100 femtoseconds for such research 24 hours per day since 2018. After one year operation, the pulse energy and spectra of DCLS has been improved to be very stable. More and more users are interested with this new light source in VUV range. On the other hands beamtime is limited because of LINAC and single undulator line. The second FEL line of DCLS, which will be installed at the end of 2019, can partially settle this problem. Furthermore we are more ambitious to propose a new plan of high rep rate CW FEL machine covering from VUV to Soft X-ray. The pre-study of the project is supported by local government.

THP081 **PolFEL — New Facility in Poland**

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In 2018 funds for the free electron laser PolFEL project was received. PolFEL will be driven by cw operating superconducting linac with SRF electron source. PolFEL will generate THz, IR and VIS-VUV radiation in two beamlines, respectively. In the first one, with electron beam below 80 MeV, the THz/IR radiation source will be generated in permanent magnet supper-radiant undulator, delivering THz radiation in 0.5 to 6 THz range. In the second beam line with up to 180 MeV electrons, the VIS/VUV radiation will be generated in the SASE undulator delivering coherent radiation down to 55 nm wavelength in the third harmonic, with sub-100 fs pulse duration. At the moment, four end-stations are planned. Experiments will be equipped with dedicated Pump-Probe spectrometer system as well. In the project, also, the Inverse Compton Scattering experiment is planned. In this contribution we will describe PolFEL facility in more details.

THP082 **Sub-100 Femtosecond Ultrafast Electron Diffraction at KAERI**

H.W. Kim, *I.H. Baek, K.H. Jang, Y.U. Jeong, K. Lee, K. Oang, S. Park (KAERI) I.H. Baek, K.H. Jang, Y.U. Jeong, K. Lee (University of Science and Technology of Korea (UST)) J. Kim, J. Shin (KAIST) S.H. Park (KUS) N.A. Vinokurov (BINP SB RAS)*

Ultrafast electron diffraction (UED) facility was developed at the Korea Atomic Energy Research Institute for time-resolved diffraction experiments with sub-100 femtosecond temporal resolution. This facility consists of an RF photogun in conjunction with a 90-degree bending structure. The electron bunch was compressed to 30 fs with 1 pC charge by the 90-degree bending structure. Furthermore, the 90-degree bending structure satisfies an isochronous condition that can reduce a timing jitter between the electron bunch and a pump laser pulse to sub-10 fs. The temporal resolution of our UED facility was determined by measuring structural dynamics of polycrystalline bismuth sample. In this work, we will present the experimental results on temporal diagnostics of electron bunch by utilizing terahertz streak camera with a few fs accuracy, and the temporal resolution of UED beamlines as well.

THP083 **Status of the NovoFEL Facility**

***O.A. Shevchenko**, V.S. Arbuzov, K.N. Chernov, I.V. Davidyuk, O.I. Deichuli, E.N. Dementyev, B.A. Dovzhenko, Ya.V. Getmanov, Ya.I. Gorbachev, B.A. Knyazev, A.A. Kondakov, V.R. Kozak, E.V. Kozyrev, S.A. Krutikhin, V.V. Kubarev, G.N. Kulipanov, E.A. Kuper, I.V. Kuptsov, G.Y. Kurkin, A.S. Matveev, L.E. Medvedev, V.V. Repkov, T.V. Salikova, M.A. Scheglov, I.K. Sedlyarov, S.S. Serednyakov, A.N. Skrinsky, S.V. Tararyshkin, V.G. Tcheskidov, A.G. Tribendis, N.A. Vinokurov, P. Vobly, V. Volkov (BINP SB RAS) I.V. Davidyuk, Ya.V. Getmanov, B.A. Knyazev, E.V. Kozyrev, V.V. Kubarev, A.S. Matveev, S.S. Serednyakov, N.A. Vinokurov (NSU) A.G. Tribendis (NSTU)*

The Novosibirsk FEL facility comprises three FELs, installed on the first, second and fourth orbits of the multi-turn ERL. The first FEL covers the wavelength range of 90 to 240 microns at an average radiation power of up to 0.5 kW with a pulse repetition rate of 5.6 or 11.2 MHz and a peak power of up to 1 MW. The second FEL operates in the range of 40 to 80 microns at an average radiation power of up to 0.5 kW with a pulse repetition rate of 7.5 MHz and a peak power of about 1 MW. These two FELs are the world's most powerful (in terms of average power) sources of coherent narrow-band (less than 1%) radiation in their wavelength ranges. The third FEL was commissioned in 2015 to cover the wavelength range of 5 to 20 microns. Current status of the facility and user activities at all three FELs as well as plans of future upgrade will be presented.

THP084 **Status of the Soft X-Ray Laser (SXL) Project at MAX IV Laboratory**

***F. Curbis**, J. Andersson, L. Isaksson, M. Kotur, F. Lindau, E. Mansten, M.A. Pop, H. Tarawneh, P.F. Tavares, S. Thorin, S. Werin (MAX IV Laboratory, Lund University) S. Bonetti, A. Nilsson (Stockholm University) V.A. Goryashko (Uppsala University) P. Johnsson, W. Qin (Lund University) M. Larsson, P.M. Salen (FYSIKUM, AlbaNova, Stockholm University) J.A. Sellberg (KTH Physics)*

The Soft X-ray Laser (SXL) project is now in a conceptual design phase and aims to produce FEL radiation in the range of 1 to 5 nm. The FEL will be driven by the existing 3 GeV linac, which also serves as injector for the two storage rings at the MAX IV laboratory. The science case consists of experiments ranging from AMO physics to condensed matter, chemistry and imaging in life science. In this contribution, we will present the current conceptual design of the accelerator and the FEL operation modes together with a general overview of the beamline and experimental station. In particular design options for the FEL will be discussed in conjunction with the features of the electron beam from the MAX IV linac and the connection with the proposed experiments.

THP085 **Status of Athos, the Soft X-Ray FEL Line of SwissFEL**

***R. Ganter**, G. Aeppli, J. Alex, C. Arrell, V.R. Arsov, S. Bettoni, C. Bostedt, H.-H. Braun, M. Calvi, T. Celcer, P. Craievich, R. Follath, F. Frei, N. Gaiffi, Z.G. Geng, C.H. Gough, M. Huppert, R. Ischebeck, H. Jöhri, P.N. Juranič, B. Keil, F. Löhl, F. Marcellini, G. Marinkovic, G.L. Orlandi, C. Ozkan Loch, M. Paraliev, L. Patthey, M. Pedrozzi, C. Pradervand, E. Prat, S. Reiche, T. Schietinger, T. Schmidt, K. Schnorr, C. Svetina, A. Trisorio, C. Vicario, D. Voulot, U.H. Wagner, A.C. Zandonella (PSI)*

The Athos line will cover the photon energy range from 250 to 1900 eV and will operate in parallel to the hard X-ray line Aramis of SwissFEL. The paper will describe the current layout of the Athos FEL line starting from the fast kicker magnet followed by the dogleg transfer line, the small linac and the 16 APPLE undulators. From there the photon beam passes through the photonics front end and the beamline optics before reaching the experimental stations AMO and FURKA. The focus of this contribution will be on the two bunch operation commissioning (two bunches in the same RF macropulse), which started in 2018, and the characterization of the major components like the APPLE X undulator UE38, the CHIC chicane and the dechirper. The Athos installation inside the tunnel is alternating with Aramis FEL user operation and the first lasing is planned for winter 2019 / 2020.

THP086 **Operation Modes of the SwissFEL Soft X-Ray Beamline Athos**

***S. Reiche**, E. Ferrari, E. Prat (PSI)*

SwissFEL drives the two FEL beamlines Aramis and Athos, a hard and soft X-ray FEL, respectively. The layout of Athos extends from a simple SASE FEL beamline with the addition of delaying chicanes, external seeding and beam manipulation with wakefield sources (dechirper). It reserves also the space for a possible upgrade to self-seeding. This presentation gives an overview on the detailed layout enabling the unique operation modes of the Athos facility.

THP087 **Grow of Momentum Spread in an Ultrarelativistic Electron Beam at Spontaneous Emission Mode**

***V.V. Ognivenko** (NSC/KIPT)*

The motion of an ultrarelativistic electron beam in a helical undulator is considered taking into account the spontaneous incoherent fields produced by individual electrons. We investigate the influence of such fields on change in mean square momentum of electrons at initial stage of interaction between radiation field and electrons when the motion of electrons is defined by pair interaction forces. For small value of undulator parameter the analytical expressions of this force and diffusion coefficient are obtained for electrons with different initial energy. It is shown that at a stage of spontaneous incoherent radiation there is an increase of mean square spread in momentum of electrons. Dependences of mean square spread in momentum from a distance passed electrons in an undulator are found. It is shown that in initially monoenergetic electron beam a mean square spread due to influence of the incoherent fields on electrons motion may have a predominant effect compared with a spread caused by quantum fluctuations of undulator radiation. The possibilities of decrease of coherent radiation wavelength in an X-ray FELs are discussed.

THD — Thursday - Late Afternoon

Chair: S. Biedron (Argonne National Laboratory, Office of Naval Research Project)

THD01 16:15 30 **From Femtosecond to Attosecond Coherent Undulator Pulses**

***V.A. Goryashko**, P.M. Salen, G.K. Shamuilov (Uppsala University)*

In Bohr's model of the hydrogen atom, the ground-state electron completes one cycle of revolution in 150 attoseconds. Some other processes in atoms and molecules can be even faster. Femtosecond and attosecond pulses of light can provide the resolution needed for studying and ultimately controlling the dynamics of electrons in solids, molecules and atoms. Therefore, there is a strong scientific demand for the development of sources of high-energy, ultrashort, coherent, X-ray pulses. In this talk, we (i) review the characteristic time and length scales in atoms, molecules and nanostructures, (ii) outline the progress on short-pulse generation over time and the state-of-the-art of production of high-energy, ultrashort pulses; (iii) examine the demonstrated and proposed schemes of the generation of femtosecond and sub-femtosecond pulses with FELs, (iv) discuss recent concepts for the production of 100-attosecond pulses.

THD02 16:45 30 **Attosecond Pulses from Enhanced SASE at LCLS**

***A. Marinelli**, P.H. Bucksbaum, E. Champenois, J. Cryan, T.D.C. Driver, J.P. Duris, Z. Huang, A.A. Lutman, J.P. MacArthur, Z. Zhang (SLAC) Z. Huang, S. Li, J.P. MacArthur (Stanford University) M. Kling, P. Rosenberger (LMU) A. Zholents (ANL)*

In my talk I will report the generation and diagnostic of GW-scale soft X-ray attosecond pulses with a current-enhanced X-ray free-electron laser. Our method is based on the enhaced SASE scheme, where an electron bunch with high-current spike is generated by the interaction of the relativistic electrons with a high-power infrared pulse. The X-ray pulses generated by the compressed electron beam are diagnosed with angular photoelectron streaking, and have a mean pulse duration of 350 attoseconds. Our source has a peak brightness that is 6 orders of magnitude larger than any other source of isolated attosecond pulses in the soft X-ray spectral region. This unique combination of high intensity, high photon energy and pulse duration enables the investigation of valence electron dynamics with non-linear spectroscopy and single-shot imaging. I will also discuss the generation of two-color attosecond pulses and our future plans for attosecond science at LCLS-II.

THD03 17:15 30 **FEL Optimization: From Model-Free to Model-Dependent Approaches and ML Prospects**

***S. Tomin**, G. Geloni (EuXFEL) Ye. Fomin (NRC) M. Scholz (DESY)*

Users beam-time at modern FEL sources is an extremely valuable commodity. Moreover, maximization of FEL up-time must always be performed accounting for stringent requirements on the photon pulse characteristics. These may vary widely depending on the users requests, which poses issues to parallel operation of high-repetition rate facilities like the European XFEL. Therefore, both model-free or model-dependent optimization schemes, where the model might be given, or provided by machine-learning approaches, are of high importance for the overall efficiency of FEL facilities. In this contribution, we review our previous activities and we report on current efforts and progress in FEL optimization schemes at the European XFEL. Finally, we provide an outlook on future developments.

THD04 17:45 15 **A Novel Optical Undulator Using Array of Pulse-Front Tilted Laser Beams**

***W. Liu** (USTC/NSRL)*

We report a laser-driven undulator for developing compact ultraviolet-to-X free-electron lasers (FELs), which overcomes the main disadvantages of previous optical and magnetic undulators. It uses an array of transverse-polarized laser beams with alternated phases to provide the periodic deflecting fields. The pulse-front tilt is applied to free the undulating period from the laser wavelength. The transverse electric field of laser is to deflect the electrons in the vacuum, which greatly increases the efficiency and the achievable deflecting forces since it avoids the breakdown of medium. The ultraviolet-to-X FEL with a desirable undulator strength can be achieved by lasers with intensities being orders of magnitude less than that in previous optical undulator, and by electrons with energies being remarkably less than that of magnetic undulator. Thus, it affords a promising way for developing the ultra-compact and powerful FELs.

FRA — Friday - Early Morning

FRA01 09:00 30 **FEL Operation at the European XFEL Facility**

D. Nölle *(DESY)*

The European XFEL is a SASE FEL based user facility in the metropole region of Hamburg providing hard and soft X-ray photons with extremely high brilliance. The three FEL lines are operated simultaneously and are powered by a superconducting LINAC based on TESLA technology. Average power levels of up to several W have been demonstrated as well for soft and hard X-rays and can be requested by user experiments on day by day basis. The contribution will report on the results of the commissioning within the last two years as well as on the transition to user operation. Typical operation conditions for parallel operation of 3 SASE lines will be discussed. The perspective for the operation with an extended photon energy range, as well as for full power operation with up to 27000 pulses per second will be presented.

FRA02 09:30 30 **LCLS-II - Status and Upgrades**

A. Brachmann*, M. Dunham, J.F. Schmerge (SLAC)*

The LCLS-II FEL is under construction at the SLAC National Accelerator Laboratory. This facility is based on a superconducting accelerator, providing a cw e^- beam of 4 GeV at ~1 MHz. This beam drives two variable gap undulator (VGU) beam lines to generate photons in the soft and hard X-ray regime. High repetition rate photon beams will be available up to ~5 keV. The normal conducting accelerator will remain in operation, delivering milli-joule pulses up to ~20 keV for LCLS science. We anticipate to start the LCLS user program in the spring of 2020 using the new undulator systems. Superconducting accelerator operation will start in 2021 and will achieve full design-performance over the course of several years. Approximately a quarter of the superconducting accelerator is installed now and the associated cryoplant construction is near completion. The VGU systems will be installed and ready for beam delivery in early 2020. We will report on the project status, commissioning and ramp-up plans to achieve design performance and discuss plans to take advantage of the new facilities potential including our longer term strategy to extend the capability of SLAC's LCLS FEL facility.

FRA03 10:00 30 **FLASH - Status and Upgrades**

J. Rönsch-Schulenburg *(DESY)*

FLASH, the Free-Electron Laser at DESY in Hamburg was the first FEL user facility in the XUV and soft X-ray range. The superconducting RF technology allows to produce several thousand SASE pulses per second with a high peak and average brilliance. It developed to a user facility with a 1.25 GeV linear accelerator, two undulator beamlines running in parallel, and a third electron beamline containing the FLASHForward plasma wakefield experiment. Actual user operation and FEL research are discussed. New concepts and a redesign of the facility are developed to ensure that also in future FLASH will allow cutting-edge research. Upgrade plans are discussed in the contribution.

FRA04 10:30 30 **Status of SXFEL Test and User Facilities**

Z.T. Zhao *(SSRF)*

Shanghai soft X-ray Free-Electron Laser facility (SXFEL) is being developed in two steps, the test facility SXFEL-TF and the user facility SXFEL-UF. The SXFEL-TF, as a critical development step towards constructing a soft X-ray FEL user facility in China, is under commissioning at the SSRF campus. In the meantime, the SXFEL-UF with designed wavelength in the water window region is being constructed, based on upgrading the SXFEL linac energy to 1.5 GeV and building two undulator lines and five experimental stations. In this paper, we report the construction and commissioning status and future plan of the SXFEL facility.

Boldface papercodes indicate primary authors

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	Monday 26.8.2019	Tuesday 27.8.2019	Wednesday 28.8.2019	Thursday 29.8.2019	Friday 30.8.2019
Location	Universität Hamburg, Main Building				DESY, Auditorium
08:00	Registration				
08:15					
08:30					
08:45					
09:00		SASE FEL	Electron sources	FEL applications	Status of projects and facilities 2
09:15					
09:30					
09:45					
10:00	Welcome Address Memorial Talk First Lasing				
10:15					
10:30		Coffee Break	Coffee Break		
10:45				Coffee Break	
11:00		Seeded FEL	Electron diagnostics, timing, synchronization, and controls		Conluding Remarks Tour Introduction
11:15				Electron beam dynamics	
11:30	Coffee Break				Coffee Break
11:45					
12:00	Status of projects and facilities 1				Laboratory Visits EuXFEL FLASH
12:15					
12:30					
12:45		Lunch Break	Lunch Break	Lunch Break	
13:00	Lunch Break				
13:15					
13:30					Lunch Break
13:45					
14:00					
14:15		Poster Session	Poster Session	Poster Session	
14:30	FEL 2017 Prize Talks				
14:45					
15:00					Laboratory Visits EuXFEL FLASH
15:15					
15:30					
15:45	Coffee Break	Coffee Break	Coffee Break	Coffee Break	
16:00					
16:15	FEL Theory	FEL oscillators and long wavelengths FEL	Photon beamline instrumentation and undulators	Novel concepts and techniques	
16:30					End of Conference
16:45					
17:00					
17:15					
17:30					
17:45	Break	Break	Break		
18:00		Tutorial	Tutorial	Break	
18:15					
18:30					
18:45					
19:00	Welcome Reception			Conference Dinner	
23:00					